



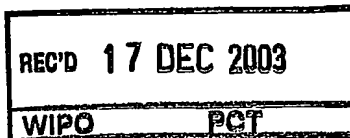
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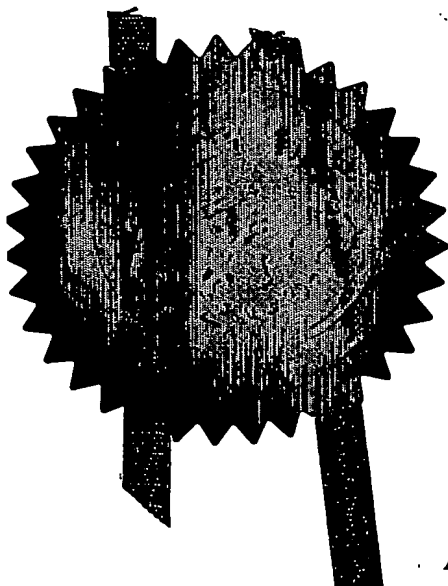


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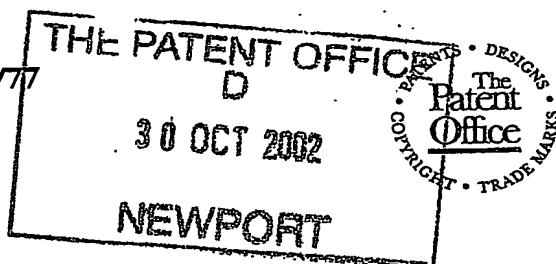
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4. Title of the invention Electronic Components

5. Name of your agent (if you have one)

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Hewlett-Packard Ltd, IP Section
Filton Road, Stoke Gifford
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ELECTRONIC COMPONENTS

Field of the Invention

The present invention relates generally to low cost electronic components and circuitry and to methods and apparatus for manufacturing such electronic components and circuitry.

Background to the Invention

Semiconductor fabrication traditionally employs a series of technologically demanding steps. For instance in the case of the manufacture of high performance transistors these may include: vacuum deposition methods to deposit conductors, followed by the application of photo-resist, exposing, developing, etching and then dopant implantation. Such methods must be performed in a clean room environment to prevent contamination of the substrate that would result in gaps in the metal layers or photo-resists. Additionally, they require the use of dangerous chemicals that necessitate the adoption of stringent safety procedures. These processes result in the requirement of a large capital investment. Consequently, the final product is relatively expensive.

Over recent years the demand for low-cost electronics has grown significantly. This is especially true in technological areas which have up until now not been associated with the use of electronics, such as clothing, packaging, or retail items.

It would therefore be desirable to provide electronic components and a method and apparatus for manufacturing such electronic components, which address the problems found in the prior art.

Summary of the Invention

According to one aspect of the present invention there is provided a method of manufacturing an electronic component having an electrical characteristic dependent upon its geometry, comprising the step of defining at least one aspect of the geometry of the component using a contact lithographic printing process.

By using a contact lithographic printing process to define one or more dimensions in an electronic component, various advantages may be realised. In embodiments of the present invention, accurately manufactured electronic components may be
5 fabricated without the need for expensive photomasks, as in conventional in electronics manufacture. This in itself brings important benefits. Photomasks or screen printing masks of a size of 6 inches by 6 inches currently may cost thousands of dollars, and once made, the design of a photomask or of a screen printing masks is fixed. Thus, as new circuit designs are required, possibly with slight repositioning
10 of components, new masks must be produced. Thus, by obviating the need for such masks, appreciable cost savings may be made. Furthermore, photomasks or a screen printing masks suffer from the disadvantage of covering a relatively small area. The maximum size of such masks is limited, which in turn constrains the use to which they may be put. Furthermore, by eliminating the need for photomasks,
15 other conventional processes used in the fabrication of electronics such as exposing, developing, etching and dopant implantation may also be eliminated in embodiments of the present invention. Consequently, the reliance upon a clean room environment and hazardous chemical may be avoided. In this manner, the cost of electronic components or circuits according to embodiments of the invention may be
20 significantly less than that of conventionally produced components or circuits.

In preferred embodiments of the present invention, the correct positions and orientations of electronic components and their individual structures may be determined accurately over large distances through the use of conventional artificial
25 imaging and/or position measurement systems. This obviates the need for expensive XY tables associated with conventional electronics manufacturing methods. Since, artificial imaging systems need not be specific to a particular design of circuit, manufacturing systems according to embodiments of the present invention lend themselves well to being reconfigured in a flexible manner without significant
30 system redesign being required.

In preferred embodiments of the present invention, electronic circuits, which include electronic components according to embodiments of the present invention, may be constructed in an integrated manner. Circuits according to certain embodiments of the invention may be constructed on a wide range of substrates, including substrates other than silicon; for example, large dimensioned sheets of inexpensive plastics materials. This means that comparatively large circuits may relatively readily be produced. Furthermore, by using a flexible substrate, electronics components and circuits according to embodiments of the present invention are suitable for use in fields where non-rigid electronic circuitry is required; for example clothing or retail.

Preferably, the first material is printed in a predetermined pattern on a substrate in the contact lithographic printing process. Preferably, a second material, which forms a structure of the component, is deposited onto the substrate such that it adopts a geometry that conforms to the pattern of the first material by virtue of hydrophilic-hydrophobic interaction. In a preferred embodiment, the contact lithographic printing process accurately prints a pattern on the substrate with hydrophobic ink. A structure of the component is then deposited on the substrate in the form of a hydrophilic fluid. The one or more dimensions of the structure of the component may be accurately controlled by the presence of the precisely printed hydrophobic ink.

Preferably, the second material is deposited using printing techniques, such as inkjet techniques.

Preferably, the hydrophobic material is paraffin wax, or similar material dissolved in a low boiling point solvent such as styrene. The solvent allows the paraffin wax to be thinned to a suitable consistency to facilitate the processes of loading a stamp with the wax and transferring the wax to the substrate. However, once the transfer has been made, the styrene readily evaporates leaving paraffin wax occupying the desired area on the substrate. As the styrene evaporates, the density and viscosity of the transferred material increases and its mobility decreases. The low mobility characteristic of the residual paraffin wax is desirable since it helps to ensure that the paraffin wax continues to occupy the desired area on the substrate even when other

substances are deposited on or adjacent to the paraffin wax. In this manner, the required dimensions of the component under construction may be accurately and reliably controlled.

- 5 Preferably, the contact lithographic process employed is a soft contact lithographic printing process. A soft contact lithographic process allows a contact stamp to conform to the surface of the substrate on to which the material, such as paraffin wax, is being transferred. This helps to ensure that the material transfer is acceptably uniform and repeatable. In one preferred embodiment, a rubber stamp of
- 10 PDMS (polydimethylsiloxane) material is used. In other embodiments, a hard stamp may be used in conjunction with a soft substrate material, whilst retaining the benefit of the soft contact process.

- 15 In one preferred embodiment of the invention, a soft contact lithographic printing process is used to accurately control the gate length of transistors. As is understood in the art, as the gate length dimension of a transistor increases, the current which is needed to switch the transistor also increases. Therefore, in order to reduce the power consumption of a transistor, it is preferable that the gate length dimension is relatively small. Furthermore, in order to ensure that all like transistors in a given
- 20 circuit, or in corresponding circuits, have similar characteristics or that their characteristics are reproducible, it is preferable that they have similar relevant dimensions.

- 25 In preferred embodiments, inkjet printing techniques are used to precisely deliver of fluids carrying nanoparticles of semiconductor, insulator, conductor, or electrode material etc. on to the surface of the substrate to build up electronic components and circuits. In other embodiments, other printing techniques such as offset lithographic (photogravure) or digital offset printing methods are employed. Using such techniques allows the use of specific high performance materials with which relatively
- 30 high performance electronic circuits may be produced; thus, providing performance that is significantly higher than of circuits using semi-conducting polymers, for example. For example, high electron mobility doped silicon, for use in transistor.

gates may be employed, together with high conductivity gold and copper contacts. Preferably this is carried out in a completely, or substantially completely, additive process, without the use of expensive or dangerous chemicals. Thus, lower materials costs are incurred and little waste is produced. Consequently, methods according to the invention may have a reduced environmental impact compared to conventional methods.

Preferably, certain structures of electronic components of embodiments of the invention are heat treated using lasers. In this manner, different materials in electronic components may be annealed, recrystallized, dried or ablated, for example, after being deposited on the substrate.

The present invention also extends to the apparatus for manufacturing electronics components, such as transistors, or resistors, or capacitors corresponding to the claimed methods, as well as circuits comprising such components.

Furthermore, the present invention extends to electronic components, such as transistors, or resistors, or capacitors, manufactured in accordance with the present invention, or circuits incorporating such electronic components.

The present invention also extends to a computer program, arranged to implement the methods of the present invention.

Brief Description of the Drawings

For a better understanding of the invention and to show how the same may be carried into effect, there will now be described by way of example only, specific embodiments, methods and processes according to the present invention with reference to the accompanying drawings in which:

Figures 1 to 6 schematically illustrate the fabrication process of a stamp suitable for use in accordance with one embodiment of the present invention;

Figures 7 to 15 schematically illustrate the process by which a stamp may be inked, aligned with and printed on a substrate in accordance with one embodiment of the present invention;

5 Figures 16a-n schematically illustrate a method of constructing transistors according to one embodiment of the invention;

Figures 17a-h schematically illustrate a method of constructing resistors according to one embodiment of the invention; and,

Figures 18a-k schematically illustrates a method of constructing capacitors according to one embodiment of the invention.

10

Detailed Description of the Best Mode for Carrying Out the Invention

There will now be described examples of the best mode contemplated by the inventors for carrying out the invention.

15 As has been described above, in preferred embodiments of the invention stamps are inked such that they retain an oleophilic, or hydrophobic, liquid on features of their surfaces. The oleophilic liquid is then transferred through a soft-contact-lithography stamping, or printing process to the desired location on a substrate on which one or more electronic components or circuits are to be constructed. When this same area
20 has hydrophilic solutions or inks deposited on it or adjacent to it, separation occurs between the oleophilic and hydrophilic regions. This technique is used in preferred embodiments to help define specific or critical dimensions of electrical components such as the dimensions of gates for transistors.

25 Below, the manufacturing process for a stamp for use in the present embodiment is described, as are suitable techniques for inking and aligning the manufactured stamp, prior to carrying out a stamping operation. Subsequently, apparatus and processes for manufacturing three different types of electronic components according to the methods of the present embodiment are described. These
30 components are: transistors; capacitors; and, resistors.

Manufacture of Stamp

Referring to Figure 1a, a small section of conventional silicon wafer 2 is illustrated. The wafer is covered a conventional photoresist material 4. The photo resist is then exposed through a mask 6, illustrated in Figure 1b, with the shape 8 of the desired stamp feature. Any suitable type of mask may be used, for example a chrome mask. In this manner, all of the photo resist on the wafer may be exposed or cured except the area 10 corresponding to the pattern. The uncured photo resist is then washed away, leaving a cut out or recess 12 corresponding to the shape of the desired stamp. This forms a mould as is illustrated in Figure 2.

A suitable material for manufacturing the stamp is then prepared. In this example, a PDMS (polydimethylsiloxane) material, a synthetic polymer of repeating $[(CH)_3SiO]$ units, is used. A suitable commercially available PDMS system is Sylgard Elastomer 184TM, available from Dow Corning TM. This material is supplied as a 2-part kit comprising of a base and a curing agent. Combining the base and curing agent together causes a reaction. The relative proportions of the base and the curing agent determine the degree of cross-linking; which in turn determines the hardness or softness of the material.

The required hardness of the PDMS material may be determined by experimentation, to match particular operational requirements. However, it has been found that one suitable preparation of the PDMS material is obtained by mixing the base and curing agent solution of the PDMS in the ratio of 1 part of curing agent to 10 parts of base material. This is stirred to ensure a homogenous mixture and set aside for 15 minutes to allow bubbles to be expelled. The prepared PDMS mixture 14 is poured onto the mould, as is illustrated in Figure 3, and set aside for 15 minutes to allow gas bubbles to be expelled. The PDMS is then cured at 130°C for 20 minutes in a conventional manner.

An aluminium backing plate 16 is subsequently bonded onto the cured PDMS as is illustrated in Figure 4. The cured PDMS together with the aluminium backing plate is

then removed to reveal a positive, soft stamping structure 18, illustrated in Figure 5. In this example, only one stamp feature is shown. However, in practice a complete stamp may be fully populated with features, as is schematically illustrated in Figure 6.

5 Inking of Stamp

Figures 7a and 7b illustrate a side view and a plan view, respectively, of an apparatus used to ink the stamp in the present embodiment. As can be seen from the figures, the PDMS stamp 18 is located in a frame 20, which in turn is mounted on four vertical bearing shafts 22. A motorised vertical or Z axis 24 is also provided to allow the stamp to be precisely raised and lower over a range of approximately 4 millimetres in the present embodiment. In this example, the motorised Z axis is provided by a stepper motor 24a and lead screw 24b.

Beneath the stamp 18 and the frame 20, and attached to the frame by two linear slides (not shown), is a moveable stainless steel flat plate or tray 26, that has a recessed area 28 slightly bigger than the stamp. In this example, the recessed area is milled down to a depth of approximately ten microns. This area provides a recess arranged to retain the hydrophobic liquid or ink. Above the tray and laterally offset to the stamp is an array of conventional air assisted micro-dispensing nozzles 30. Parallel to the array of nozzles is a conventional PDMS squeegee or doctor-blade 32.

The process by which the stamp may be inked will now be described with reference to Figures 7 to 13, which show the apparatus used to ink the stamp during different stages of the inking process. It will be noted that Figures 8a, 9a and 10a each show a side view of the apparatus, corresponding to that shown in Figure 7a and that Figures 8b, 9b and 10b each show a side view of the apparatus, corresponding to that shown in Figure 7b.

The operation of the inking cycle commences with the inking apparatus in the "load" position, as illustrated in Figure 7, with the tray, with no ink in it, located under the stamp.

The tray then unloads, as is illustrated in Figures 8a and 8b, the tray passing beneath the array of nozzles 30 in the direction of the arrow in Figure 8a. As it does so, the nozzles dispense hydrophobic liquid or ink 34, eventually covering the entire recessed surface of the tray. In this example, the hydrophobic liquid 34 is a paraffin wax dissolved in a low boiling point solvent such as styrene, although any other suitable material may alternatively be used. In the present embodiment, the hydrophobic liquid 34 contains a conventional fluorescent marker dye. This facilitates the process of identifying the location of the hydrophobic liquid 34 once it has been transferred or stamped onto a substrate. As can be seen from the figures, the squeegee 32 and the stamp 18 are in their raised positions during this unloading phase.

The tray then loads once again; i.e. moves in the direction of the arrow in Figure 9a. During this loading phase, the stamp is in its raised position but the squeegee 32 is lowered. As the tray is loaded, the squeegee wipes excess ink from the entire recessed tray surface, leaving a uniform thickness of ink on the tray, as is illustrated in Figure 10.

On completion of the loading phase, the stamp and ink-plate are mutually aligned. The stepper motor then rotates the lead-screw connected to the back of stamp frame, lowering the stamp, as is indicated by the arrow in Figure 12. The stamp is lowered until contact is made between the feature or features on the stamp-face and the ink. Only the features on the face of the stamp are brought into contact with the ink in the tray.

The stamp is then withdrawn at a controlled rate as is illustrated by the arrow in Figure 13a. This allows the surface tension to separate the ink on the face of the stamp from that in the tray. This is illustrated by the Figures 13b and 13c, which illustrate an enlarged view of the circle area in Figure 13a. Figure 13b shows the progressive separation of the of the ink 34a on the stamp from the ink 34 in the tray under the effect of surface tension as the stamp moves away from the tray in the

direction indicated by the arrows in the figure. Figure 13c illustrates the ink 34a retained on the features of the stamp when the stamp has been fully withdrawn from the tray. Although other inking processes may be used, the inking process described gives repeatable results in terms of the amount of ink that is loaded onto the stamp.

5

Alignment and printing of stamp

Once a stamp has been loaded with ink, it is ready to be aligned with a substrate on which one or more electronic components circuits are to be constructed, so that the ink may be transferred to the substrate. This process will now be described with
10 reference to Figures 14a, 15a and 15b.

15

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Figure 14a illustrates the apparatus used in the present embodiment to position and align a stamp with the substrate such that the ink on the stamp may be applied to the substrate. As can be seen from the figure, the combined stamp and tray assembly, shown in Figures 7 to 13, is mounted on a scanning carriage 38. In Figure 14a the combined stamp and tray assembly is referenced 36. The scanning carriage is arranged to move along two parallel guides 40, by virtue of a conventional drive motor. A code strip 42a and a code strip reader 42b are used to register the position of the carriage in the scanning, or "X" direction. The substrate (not shown) may be
moved as a pre-cut sheet or from a roll in the "Y" direction, perpendicular to the "X" direction, as is indicated in the figure. This may be achieved using a conventional media feeding system (not shown) arranged to feed the substrate over a conventional supporting surface or platen, which supports the substrate whilst being printed on. The scanning carriage 38, the guides 40, the code strip 42a, the code
strip reader 42b, together with the carriage scan axis drive system, the media feed system and platen may be similar or the same as similar components used in conventional printers, such as wide format scanning inkjet printers.

30

The position of the stamp-tray assembly may be precisely adjusted in the substrate-movement, or "Y" direction, by means of two stepper motor drives 44a and 44b. Also located on the carriage, to either side of the stamp are two cameras 46a and 46b that are connected to a conventional motion-image analysis system 48, or artificial

vision system. In the present embodiment, the function of the motion-image analysis system is carried out by a suitable program module or processor module 48 of a suitably programmed general purpose or dedicated computer 54, as is schematically illustrated in the figure. The computer 54 is arranged to input and output data and
5 operating instructions via conventional communications channels, here schematically represented as a cable 56.

Initially, the stamp is positioned and aligned approximately with the desired area of the substrate. This may be carried out manually by the operator of the system, for
10 example. The stamp, which is loaded with ink 34a, is then stamped onto the substrate. This is carried out by lowering the stamp with the motorised vertical or Z axis 24, as described above. During this process, the tray 26 is in a retracted position so as not to obstruct the stroke of the stamp. An alignment/position checking procedure is then carried out by the motion-image analysis to ensure that
15 the stamp was correctly positioned with respect to the substrate and to allow for the correction for any errors in the alignment/position of the stamp that may be required. This is carried out in the following manner.

In the present embodiment, in addition to printing hydrophobic regions that define
20 critical dimensions of electronic components, the stamp is arranged to print in a stamping operation a pair of test boxes, or other suitable shapes or patterns. The substrate has pre-printed on it a number of corresponding pairs of test boxes in known positions. The test boxes of the stamp and the substrate are arranged such that when the stamp is printed in the correct position and orientation relative to the
25 substrate, the two sets of test boxes will be arranged in a predetermined, and measurable position and orientation with respect to each other.

This process is illustrated in Figure 15. In Figure 15a, two test boxes 58a and 58b, which have been pre-printed on the substrate, are shown. Two smaller hydrophobic
30 test boxes 60a and 60b, printed in an alignment/position check procedure by the stamp are also shown. As can be seen from the figure, in this example the test boxes 60a and 60b each lie inside their corresponding pre-printed test boxes 58a

Examples of processes used to manufacture three different types of electronic components according to the present embodiment will now be described. In each case, various processes may be involved in addition to area selection using hydrophobic (oleophilic) stamps as is described above. These processes include, the delivery of fluid carrying nanoparticles of semiconductor, insulator, conductor, or electrode material, and their subsequent annealing, and recrystallization using lasers. Although, the processes for manufacturing electronic components according to embodiments of the present invention may take many forms, from very small scale essentially manual operations up to fully equipped production lines, in the present example, a line process is described.

Figures 14b, 14c and 14d illustrate the lines used in the present embodiment of the invention to manufacture transistors, resistor and capacitors respectively. Although each of these lines is illustrated as being a separate line, this is only for ease of explanation. In practice, the process stages of each of the lines illustrated in Figures 14b, 14c and 14d may be combined such that one line may produce each of the three types of electronic components, integrated in electronic circuits for example.

Each of the lines illustrated in Figures 14b, 14c and 14d illustrate two views of the respective line process. Figures 14b₁, 14c₁ and 14d₁ illustrate the respective processes in plan view. Figures 14b₂, 14c₂ and 14d₂ illustrate the respective processes in side view. The three processes share a number of common features. These will be explained together. A moving substrate 70 is driven conventionally from a first roller 72 to a second roller 74, in the direction of the arrow. This corresponds to the "Y" direction illustrated in Figure 14a. In the present example, the substrate 70 is a flexible sheet, which is supported on a suitable platen (not shown). The substrate 70 may be any suitable material, for example polyethylene terephthalate (PET). However, in other examples, rigid, or non-flexible substrates such as silicon may instead be used, in conjunction with a suitable transport path.

Certain line processes include one or more laser stations (for example station 96 in Figure 14b). These are used to carry out processes such as the annealing, recrystallization, trimming and drying of materials on the substrate. In the present invention, each laser station is equipped with a pair of cameras 80 (referenced in Figure 14c) the output of which are connected to the motion-image analysis system 48.

The process stations are configured in the present embodiments to traverse the substrate in the "X" direction, so as to access the correct portion of the substrate. This may be carried out in any convenient manner. For example, conventional scanning inkjet assemblies may be used. These may employ the architecture (not shown) of conventional wide format scanning inkjet printers. This architecture is well understood by the skilled reader and so will not be described in detail here. However, it may include, a scanning carriage mounted on guide rails, which form the scanning axis. A conventional carriage scan axis drive system may be used to propel the carriage along the axis. A code strip reader mounted on the carriage may be used to read a static code strip mounted parallel to the scanning axis. In this manner, carriage position and speed information may be derived. Again the "X" axis position control is controlled by the computer 54.

Alternatively, in the case of the inkjet stations, printheads arranged in the form of print bars or arrays of printheads that are statically mounted, such that they span the required width of the substrate in the X-axis, may instead be used. Examples of print bars suitable for use in the present embodiment are disclosed in: US Patent US6428145 B1, entitled "Wide-array inkjet printhead assembly with internal electrical routing system"; US5719602 A1, entitled "Controlling PWA inkjet nozzle timing as a function of media speed"; and, US5734394 A1, entitled "Kinematically fixing flex circuit to PWA printbar". Each of these references is in the name of Hewlett-Packard Co. and is hereby incorporated by reference in its entirety.

In the case of the laser stations, the analysis of the motion-image analysis system 48 is used by the computer 52 to precisely control the movement of each of the laser stations in the "X" direction, such that the laser in question is correctly positioned relative to a feature of interest on the substrate. The correct positioning of the lasers is determined relative to conventional vision alignment marks 81, referenced in Figure 14c. Each of the lasers of the laser stations may be pulsed on and off under the control of a laser controller, in order to implement the process of the corresponding laser station. In the present embodiment, the function of the laser controller is carried out by a suitable program module or processor module 50 of a suitably programmed general purpose or dedicated computer 54, as is schematically illustrated in Figure 14a.

In general, the processes of the present embodiment are controlled by the computer 54. Thus, the computer 54 is arranged to input and output a variety of data and operating instructions in a conventional manner. For example, it may input operating instructions from an operator, signals output by the cameras, position information output by the code strip reader or the substrate feed mechanism. The computer 54 may also, for example, output drive signals to the carriage scan axis drive system, the substrate feed system, fire signals to the inkjet printheads, printing and inking actuation commands to the combined stamp and tray assembly, and drive commands to the stepper motors and operational information to an operator.

Manufacture of transistor

Referring to Figures 16a-o together with Figure 14b, the method of constructing transistors according to the present embodiment of the invention will now be described.

Figure 16a illustrates a portion of the substrate 70 upon which one or more transistors are to be constructed. As can be seen from the figure, the substrate 70 has been pre-patterned with copper tracks 82. The copper tracks have been laid out in pre-determined positions, forming part of an electronic circuit into which two transistors will be integrated. Any conventional method of manufacturing the copper

tracks, such as traditional flex-circuit/printed circuit board processing technology, may be used.

The next step of the construction of the transistors is to form a contact 84 for the gate oxide of each transistor. In this example, the contacts are formed from a suspension of gold (Au) nanoparticles which are printed onto the surface of the substrate using one or more inkjet printheads 86 at the first inkjet station, shown in Figure 14b. In this example, two transistors are constructed, therefore, two such contacts 84a and 84b are formed, as is illustrated in Figure 16b. In the present embodiment, the gold nanoparticles are printed in a solution of water or ethyl alcohol, in a conventional manner, although any other suitable solution may instead be used. As can be seen from the figures, one end of the contact 84a is in electrical contact with an adjacent portion 82c of copper tracks. The other end of the contact 84a extends to a point on the substrate where the gate oxide of the transistor will be formed. This is approximately equidistant between the copper track portions 82g, 82c and 82b, which will connect to the drain, the gate and the source, of the transistor respectively. It will be noted that the contact 84a does not make electrical contact with the portions 82a, 82b and 82a. The contact 84b is similarly arranged relative to the portions of copper track 82d-f, as is shown in the figure.

The gold particles of the contacts 84a and 84b are then recrystallised using the laser 88 of the first laser station shown in Figure 14b. This may be done in any suitable manner. For example, using a low fluence (150 to 350 mJ/cm²) XeCL pulsed eximer laser ($\lambda = 308\text{nm}$, pulse duration = 35ns). This process is illustrated in Figure 16c, where areas 90a and 90b indicate approximately the areas influenced by the laser.

The gate oxides 92a and 92b are then formed in the case of both transistors, as is shown in Figure 16d. The gate oxide is formed from particles of SiO₂, which are printed in a solution of water or ethyl alcohol by one or more inkjet printheads 94 at the second inkjet station, shown in Figure 14b. It will be noted that each gate oxide

92a and 92b is printed in electrical contact with its respective gate oxide contact portion 84a, 84b but not in electrical contact with the portions of copper track 84a, 84b, 84g or 84d, 84f.

5 The gate oxides 92a and 92b are subsequently recrystallised, as is illustrated in Figure 16e. This is carried out by the laser of the second laser station 96 shown in Figure 14b. This may be implemented in the same manner as described above with regard to the recrystallisation of the gate contacts 84a and 84b. The laser power, wavelength, and pulse width required for efficient recrystallization need to be
10 determined empirically but power may generally be within the range of 100-500mJ.cm⁻². The areas 98a and 98b, shown in Figure 16e, illustrate the approximate areas influenced by the laser during the recrystallisation process.

A stamp 100 with PDMS stamping features, similar to those shown in Figure 6 or 7,
15 is used to stamp each gate oxide region with hydrophobic ink, in the manner described above. This stamp is operated at the lithographic printing station 102 in Figure 14b. As can be seen from Figure 16f, the stamp has two printing features 104a and 104b used to print hydrophobic ink. Each of the features has a "stripe" or band which is approximately 4 microns wide, as is schematically illustrated in the
20 figure. Each 4 micron width strip, helps to define a dimension of the gate region of the corresponding transistor, as is described below. In the present embodiment, this dimension is the gate length. In other embodiments, the stripe may have other widths, for example 1 to 15 microns. In this manner, gates of transistors with other lengths may be constructed. Indeed, the stamping process may be used to define
25 additionally or alternatively the width of the gate region of the transistors. The features 104a and 104b are aligned with the centre of the gate oxide regions 92a, 92b respectively on the flexible substrate, as is illustrated in the figure prior to the stamping process being implemented.

30 The stamp is brought into contact with the substrate, as illustrated in Figure 16g. As can be seen from this figure, each of the features 104a and 104b has the shape of a capital letter "I". These are referenced 106a and 106b in the figure.

When the stamp is removed, a residual hydrophobic region 108a and 108b is left on each gate oxide region. This is illustrated in Figure 16h. An enlarged view of one of the hydrophobic regions 108b is shown in circle "B". From the enlarged view, it can be seen that the hydrophobic regions cover all of their respective underlying gate oxide region 92 with the exception of two relatively small portions of the gate oxide. In the enlarged view, these regions are referenced 92b₁ and 92b₂. These portions lie on either side of the 4 micron wide strip, which forms the upright of the "I". This dimension of the strip is referenced in the figure by arrow "A". The regions 92a and 92b also lie between the upper and lower horizontal arms of "I".

The subsequent step is to inkjet print conventional n-doped (arsenic) silicon particles 110a and 110b, or suitable alternative, onto either side of the 4 micron wide strip, forming the upright of the "I" 108. The size of the particles may be in the range 10 - 100 nanometers and held in a suspension of water or alcohol. This is carried out by the third inkjet station 112 shown in Figure 14b. This is illustrated for one of the transistors in Figure 16i(1). The silicon suspension de-wets leaving the hydrophobic region 108 free of n-doped silicon. In other words, the hydrophobic region 108 repels the hydrophilic silicon suspension to create a clearly defined gate region of 4 microns in width; again referenced "A" in the Figure 16i(2). It will be noted from the figure, that in the present example, the silicon suspension completely covers the small portions of the gate oxide 92b₁ and 92b₂ that were not covered by the hydrophobic regions 108. It will also be noted that the n-doped silicon areas 110a and 110b extend sufficiently to overlap with and to form a satisfactory electrical contact with the portions of copper respectively forming the drain and the source connectors for the transistor. In the case of one of the transistors, these are track portions 82g and 82b, respectively. This is more clearly illustrated in Figure 16j.

A laser recrystallisation process, which may be similar to that described above, is then used to recrystallise the n-type silicon 110a and 110b. This is carried out by the laser of the third laser station 114 shown in Figure 14b. The area 115, illustrated for one of the transistors in Figure 16k, indicates approximately the area influenced by

the laser. This also has the effect of evaporating the hydrophobic layer 108 and exposing the gate oxide region that was covered by the hydrophobic ink. The resulting structure, consists of n-doped silicon portions 110a and 110b, overlying the gate oxide 92, but separated from each other by a clearly defined gate region. This is illustrated for one of the transistors in Figure 16k.

Conventional p-type silicon particles 124, or suitable alternative, are then inkjet printed onto the source, drain and gate area region of each transistor, as shown in Figure 16l. This is implemented by the fourth inkjet station 118 shown in Figure 14b. The size of the particles may be in the range 10 - 100 nanometers and held in a suspension of water or alcohol. As can be seen from the figure, in the present embodiment, the p-type silicon completely covers the gate oxide portion 92 and substantially covers the n-type silicon portions 110a and 110b.

The p-type silicon 124 is then recrystallized by the fourth laser station 122, shown in Figure 14b, in a similar manner to that described above. The recrystallized p-type silicon 126 is illustrated in Figure 16m.

Figure 16n, shows a cross a side elevation sectional view of a transistor according to the present embodiment. From the figure, the n-p-n structure of the transistor, including the drain 132, gate 134, source 136 and p-front contact 138 of the transistor may be seen.

Manufacture of resistor

Referring to Figures 17a-h together with Figure 14c, a method of constructing resistors according to the present embodiment of the invention will now be described.

Figure 17a illustrates a flexible substrate 70 upon which a resistor is to be constructed. As can be seen from the figure, the substrate has been pre-patterned with copper tracks 82a and 82b, similar to those described above, in predetermined

positions. As can be seen in the figure a space separates the copper tracks 82a and 82b, in which a resistor according to the present embodiment is to be constructed.

The next step in the process of manufacturing a resistor according to the present
5 embodiment is a soft contact lithographic printing operation, of the type described
above, which is carried out with a stamp 140 at by the lithographic printing station
142 in Figure 14c. As can be seen from the schematic Figure 17a, the stamp 140
has two PDMS printing features 144a and 144b used to print hydrophobic ink. The
features are straight lines or stripes. The length of each of the stripes is significantly
10 longer than the space separating the copper tracks 82a and 82b. The stripes are
arranged parallel to each other and spaced apart from each other by an accurately
controlled distance. In this example, the distance separating the printing features
144a and 144b is somewhat less than the width of the copper tracks 82a and 82b.

15 The stamp 140 is loaded with hydrophobic material, as described above, and aligned
with the copper tracks 82a and 82b. This is as illustrated in Figure 17b. In this
example, each of the features is aligned such that it slightly overlaps each of the
copper tracks 82a and 82b. The stamp is then brought into contact with the
substrate and removed, thus leaving residual hydrophobic regions 146a and 146b.
20 This is illustrated in Figure 17c. In this manner, an enclosed rectangular area of
substrate is created, bounded by the two copper tracks 82a and 82b and the two
hydrophobic regions 146a and 146b.

A hydrophilic resistor material 148 is then printed throughout the enclosed
25 rectangular area by an inkjet printing station 150 in Figure 14c. This is illustrated in
Figure 17d. By printing the resistor material 148 up to and over a portion of the
hydrophobic regions 146a and 146b and the copper tracks 82a and 82b it may be
ensured that resistor material 148 is printed throughout the enclosed rectangular
area. It will be appreciated that sufficient resistor material 148 is printed into this
30 region and over part of each end of the copper tracks 82a and 82b so as to
electrically connect the two the copper tracks. Preferably, this is carried out in a
uniform manner throughout the area in which the resistor material is deposited. In

In the present embodiment, this laser ablation is carried out, where required, by the laser station 152 in Figure 14c. If desired, however, a further laser station could be incorporated into the line process to undertake this process.

5 **Manufacture of capacitor**

Referring to Figures 18a to 18k together with Figure 14d, a method of constructing capacitors according to the present embodiment of the invention will now be described.

10 Figure 18a illustrates a flexible substrate 70 upon which a capacitor is to be constructed. As can be seen from the figure, the substrate 70 has been pre-patterned with copper tracks 82a and 82b, similar to those described above. As can be seen in the figure a space separates the copper tracks 82a and 82b.

15 The next step in the process of manufacturing a capacitor according to the present embodiment is a lithographic printing operation, of the type described above, which is carried out with a stamp 160 at the first lithographic printing station 162 in Figure 14d. As can be seen from the Figure 18a, the stamp 160 has PDMS a printing feature with horizontal 164a and vertical 164b elements or stripes of predetermined
20 width. The horizontal 164a and vertical 164b elements enclose a rectangular non-printing space of accurately defined width and length. This is illustrated in Figure 18b. As can be seen from the figure, the width of the rectangular non-printing space is referenced "w" and the length of the rectangular non-printing space is referenced "l" plus "g".

25 The stamp 160 is loaded with hydrophobic material and aligned with the copper tracks 82a and 82b as is indicated in Figure 18b. The stamp is then brought into contact with the substrate and removed, as described above, leaving residual a hydrophobic region bounding a non-printed rectangular space of dimensions "l" plus
30 "g" by "w", as can be seen from Figure 18b and 18c.

In the present embodiment, stamp is aligned such that the length of the rectangular non-printing space lies substantially parallel to the length of the copper track 82a and such that a length "l" of the copper track 82a lies with non-printed rectangular space. Furthermore, as can be seen from Figure 18b, the width of the rectangular non-printing space is somewhat less than the width of the track 82a and the stamp is aligned such that width of the non-printed rectangular space is arranged centrally with respect to the width of the track 82a. In this manner, there is exposed an area of the copper track 82a of width marked "w" and length "l" in the non-printed rectangular space. As can also be seen from the figures, an area of substrate material of width "w" and length "g" is also exposed in the non-printed rectangular space. This exposed area of substrate lies in the space between the tracks 82a and 82b, adjacent the end of the track 82a. Part of the hydrophobic region separates the exposed area of substrate material from the track 82b. As will be seen from the following description, this arrangement helps to avoid the risk of short circuit between different areas of the capacitor.

A hydrophilic dielectric ink 168 such as silicon dioxide particles in a solution of water is then inkjet printed throughout in the non-printed rectangular space, bounded by hydrophobic region. This is illustrated in Figure 18d and is implemented by the first inkjet printing station 170 in Figure 14d. By printing the dielectric ink 168 up to and partially over the hydrophobic printed regions, as is illustrated in the figure, it can be ensured that this whole area may be covered with the dielectric ink. Preferably, the dielectric ink is printed in a uniform manner.

As is described above with regard to the manufacture of a resistor, the dielectric ink 168 is "trimmed" by the action of the hydrophobic printed regions, which repel the hydrophilic dielectric ink 168. The trimmed area of dielectric ink 168a is illustrated in Figure 18e. As can be seen from this figure, this creates an area of dielectric with a clearly defined dimensions corresponding to the non-printing rectangular space in the stamp. The dielectric ink may then be dried. For example, by using directed laser heating or an infra-red source, not shown in Figure 14d. At the same time, the hydrophobic ink may be removed by evaporation. The area of influence of the laser,

for example, is referenced 170 in Figure 18f. The resultant structure is illustrated in Figure 18g.

A second hydrophobic region 174, is then printed in a further lithographic printing operation. This is carried out by the second lithographic printing station 172 in Figure 14d. The hydrophobic region 174 is printed, using a stamp (not shown) which is similar to the stamp 160, in that its printing element has a printing area which enclose a non-printing rectangular space.

10 The hydrophobic region 174 printed by the second lithographic printing station 172 is illustrated in Figure 18f. As can be seen from the figure, the non-printing rectangular space enclosed by the hydrophobic region 174 has a width " w_1 ", which is less than the width " w " of the non-printing rectangular space of the mask 160 and a length " l_1 " that is significantly longer than that of the non-printing rectangular space of the mask 169. The hydrophobic region 174 is positioned such that the rectangular space which it encloses spans both a portion of the copper track 82b and a portion of the dielectric area 168a, with the length of the rectangular space being approximately parallel to the length of the dielectric area 168a. Furthermore, the hydrophobic region 174 is positioned such that none of copper track 82a is exposed inside the rectangular space which it encloses.

A conductor 175, such as gold nanoparticles in water is then inkjet printed throughout the rectangular space enclosed by the hydrophobic region 174. This is illustrated in Figure 18i and is carried out by the second inkjet printing station 178 shown in Figure 14d. Since in the present embodiment, the conductor is printed in a hydrophilic solution, it is repelled by the hydrophobic area 174. Thus, the electrical conductor 175 trims to the area of the rectangular space enclosed by the hydrophobic region 174 as is illustrated in Figure 18j. In this manner, an electrical connection is formed between the copper track 82b and the dielectric area 168a, whilst no direct electrical connection is formed between the conductor 175 and the copper track 82a.

Referring to Fig 18k, this sequence of operations results in a capacitor comprising a bottom electrode of area A, equivalent to "l" multiplied by "w", a dielectric layer 168a of thickness and "d", and dielectric constant ϵ , and a top electrode 177. It will be recognized that the characteristics of the capacitor are determined by the formula $C = \epsilon.A/d$. Thus, using the process of the present embodiment, capacitors of require characteristics may be manufactures by varying the area A, or thickness "d", or dielectric constants ϵ .

Further Embodiments

It will be apparent, however, to one skilled in the art that in the above embodiment numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will though be apparent that the present invention may be practiced without limitation to these specific details. Furthermore, in other cases, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

In the embodiments described above, the construction of the various electronic components uses, at least in part inkjet printing techniques. In the described embodiment, this was implemented using scanning type inkjet printheads. In practice, this could be achieved using static Page wide arrays of inkjet printheads. Alternatively, other printing techniques, such as offset lithographic (photogravure) or digital offset printing methods, may instead be used.

Although in the above description, the stamping process is described as being implemented with a stamping surface which is raised and lowered relative to the substrate in order to implement the stamping process, it will be appreciated that in other embodiments of the invention, this need not be the case. For example, in higher throughput systems, the stamp or stamps may each be in the form of a drum. Raised features on the surface of the drum may be arranged to be loaded with hydrophobic ink, while the drum rotates. A substrate maybe driven past the drum

such that the raised features are periodically brought into contact with the substrate, thus transferring the hydrophobic ink to the substrate in desired areas.

Although a suspension of gold nanoparticles is used in this example, other suitable
5 suspensions containing particles of copper (Cu) or aluminium (Al) may also be used.

Although a method of manufacturing MOSFET transistors is described above, in a further embodiment, BIPOLAR transistors may instead be manufactured. The skilled
read will appreciate that other embodiments of the invention may be used to
10 manufacture further structures, or other types of electronic components. For
example, soft contact lithography may be used in one embodiment to provide high
accuracy hydrophobic lines of demarcation separating, inkjet printed copper
interconnects. In this manner, shorts circuits may be avoided. This may be
particularly useful, when the interconnects are tightly packed. Furthermore, RF
15 Antennas for radio frequency ID tags Antennas may be printed with enhanced
resolution using to allow more precise operation. In a further embodiment of the
invention, magnetic material may be accurately printed, using inkjet techniques for
example, using hydrophobic stamped areas to accurately control the position of the
magnetic material. Such a techniques may be used to manufacture magnetic codes
20 in printed labels. Such magnetic labels may be printed in a series of stripes and
spaces, similar to bar codes. In one such embodiment, the code may be read both
optically and magnetically for increased security. In a further embodiment, high
precision hydrophobic stamped areas may be used to allow magnetic tracks on disks
to be more densely packed to allow the recording density of the disk to be increased.

25 The skilled reader will appreciate that the various further embodiments described
herein may be used in combination with one or more of the remaining further
embodiments.

Claims:

1. A method of manufacturing an electronic component having an electrical characteristic dependent upon its geometry, comprising the step of defining at least one aspect of the geometry of the component using a contact lithographic printing process.
2. A method according to claim 1, the contact lithographic printing process printing a first material in a predetermined pattern onto a substrate, the method comprising the further step of depositing a second material onto the substrate, the second material forming a structure of the component and having a geometry that conforms to the pattern by virtue of hydrophilic-hydrophobic interaction.
3. A method according to claim 2, wherein the first material is a hydrophobic material.
4. A method according to claim 3, wherein the first material comprises a wax such as paraffin wax and a low boiling point solvent such as styrene.
5. A method according to any preceding claim, wherein the contact lithographic printing process is a soft contact lithography process.
6. A method according to claim 5, wherein the soft contact lithography process uses a stamp comprising an elastomer such as polydimethylsiloxane.
7. A method according to any preceding claim, wherein the contact lithographic printing process defines a dimension of a transistor gate, such as the gate length.
8. A method according to claim 7, wherein the contact lithographic printing process defines a dimension of a transistor gate on a gate oxide portion of the transistor, formed in a previous step.

9. A method according to claim 8 or claim 7, when dependent upon claim 2 or any one of claims 3 to 6 thereon, wherein the second material comprises doped silicon, forming the source and/or drain regions of the transistor.
- 5 10. A method according to claim 9, further comprising the step of depositing a third material comprising doped silicon, forming the gate region of the transistor.
- 10 11. A method according to claim 2, or any one of claims 3 to 11 dependent thereon, further comprising the step of removing at least a portion of the first material, by heating for example.
12. A method according to any one of claims 1 to 6, wherein the contact lithographic printing process defines a dimension of a resistor.
- 15 13. A method according to claim 12, wherein the second material comprises ruthenium dioxide or the like.
14. A method according to any one of claims 1 to 6, wherein the contact lithographic printing process defines a dimension of a capacitor.
- 20 15. A method according to claim 14, wherein the second material comprises dielectric ink, such as silicon dioxide.
- 25 16. A method according to any preceding claim, further comprising the step of depositing a conductor material arranged to connect at least a portion of the electrical component to an electrical circuit.
- 30 17. A method according to claim 16, wherein the conductor material comprises a metal such as gold, copper, or aluminium.
18. A method according to any one of claims 2, 9, 10, 13, 15, 16 or 17 wherein the second material, third material, or conductor material is deposited in a printing step.

19. A method according to claim 18, wherein the printing step comprises inkjet printing, digital offset printing, or other digital printing method.

5 20. A method according to claim 19, wherein the second material, third material, or conductor material is printed in the form of nanoparticles suspended in a suitable carried fluid.

10 21. A method according to claim 18, further comprising the step of annealing, recrystallizing or drying with a laser the second material, third material, or conductor material once after deposition.

22. A method according to any preceding claim, wherein said component is manufactured on a flexible substrate.

15

23. A method according to claim 22, wherein said substrate is a plastic material, such as PET.

20 24. A method according to claim 22 or claim 23, comprising the step of feeding the substrate from a reel substantially during the manufacture of the component.

25 25. A method according to any one of claims 22, 23 or 24, wherein the component forms part of an electrical circuit comprising one or more further components manufactured substantially simultaneously with the component on the substrate.

30 26. A method according to claim 25 when dependent upon claim 24, wherein a first dimension of the circuit is substantially unlimited in a first direction and limited in a second dimension by the width of the substrate, the width of the substrate corresponding approximately to standard paper size dimensions, such as A0, A1, A2, A3, A4, A5.

27. A method according to any preceding claim, comprising the step of determining the position and/or orientation of the contact lithographic printing process in relation to a printing substrate with an artificial imaging system.

5

28. A method of fabricating an electronic component comprising a first structure and having an electrical characteristic dependent upon the geometry of the first structure, the method comprising the steps of:

printing a precursor structure on a substrate in a soft contact lithographic process, the precursor structure having a predetermined geometry;

depositing a material on the substrate, the material forming the first structure and having a geometry conforming to the geometry of the precursor structure.

29. A method of fabricating a transistor, comprising the steps of:

transferring a first material onto a surface of a substrate in a soft contact lithographic process, the transferred material occupying a first area having a predetermined geometry; and,

printing a second material onto or adjacent said substrate, the second material being arranged to occupy an area corresponding to the first area, the second material forming the gate portion of the transistor.

30. A method of fabricating a transistor, comprising the step of sequentially inkjet printing each of a p-doped portion, an n-doped portion and a gate portion on a substrate, wherein at least one dimension of the transistor is defined using a contact lithographic printing process and the method is substantially maskless.

31. A method of fabricating a transistor on a substrate, comprising the steps of:

depositing each of a p-doped portion, an n-doped portion and a gate portion on said substrate in a substantially additive process, the gate length being defined using a contact lithographic printing process.

32. A computer program or a computer program product comprising program code for performing the method steps of any one of claims 1 to 31 when said program is run on a processing device associated with a suitable hardware.

5 33. An electronic component or circuit produced by any one of claims 1 to 31.

34. Apparatus arranged to implement the method of any one of claims 1 to 31.

10 35. An apparatus arranged to fabricate an electronic component on a substrate, the apparatus comprising a lithographic stamp arranged to transfer a predetermined pattern of hydrophobic material to the substrate, the apparatus further arranged to deposit a hydrophilic liquid adjacent or onto the pattern such that the liquid forms a structure having a geometry conforming to the pattern, the component having an electrical characteristic dependent upon the geometry of the structure.

15

36. A transistor comprising an inkjet deposited gate portion.

37. A method of manufacturing an electronic component substantially as herein described with reference to the accompanying figures.

20

38. An apparatus for manufacturing an electronic component, substantially as herein described with reference to the accompanying figures.

25 39. A electronic component, substantially as herein described with reference to the accompanying figures.

Abstract

ELECTRONIC COMPONENTS

- 5 A method of fabricating an electronic component comprising a first structure and having an electrical characteristic dependent upon the geometry of the first structure, the method comprising the steps of: printing a precursor structure on a substrate in a soft contact lithographic process, the precursor structure having a predetermined geometry; depositing a material on the substrate, the material forming the first
10 structure and having a geometry conforming to the geometry of the precursor structure.

Fig. 16n

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FIG. 1a

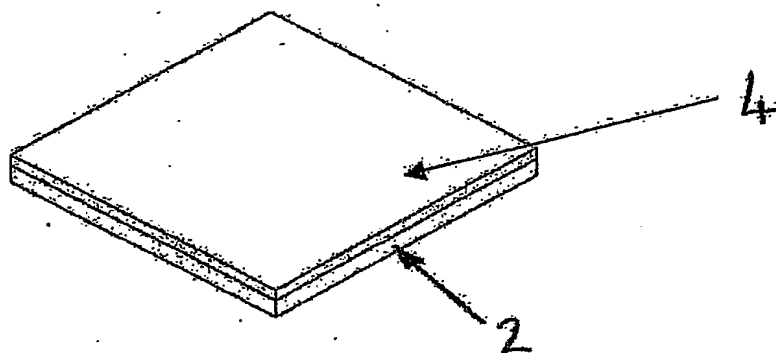


FIG. 1b

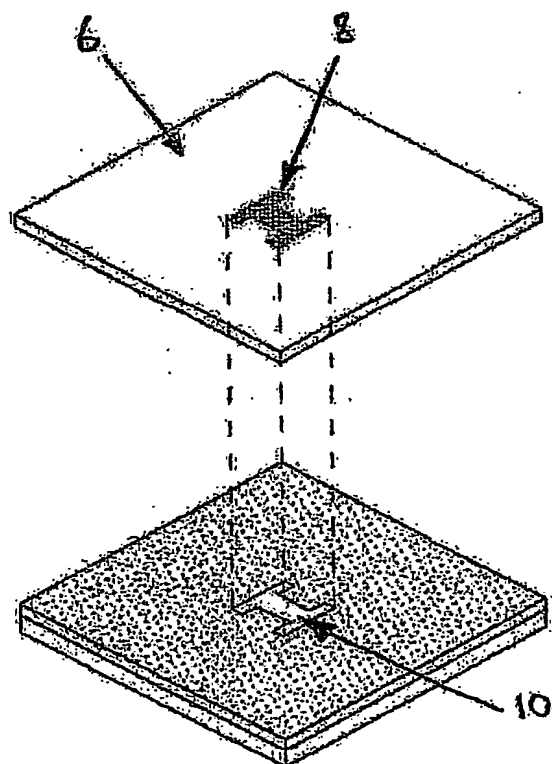


FIG. 2

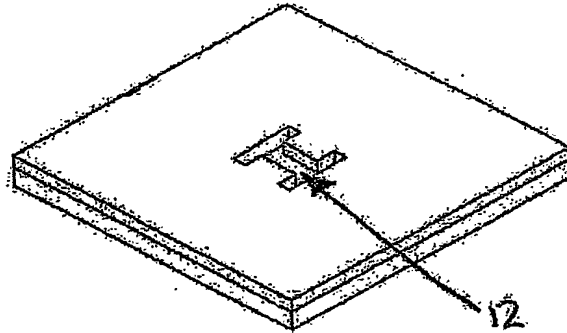


FIG. 3

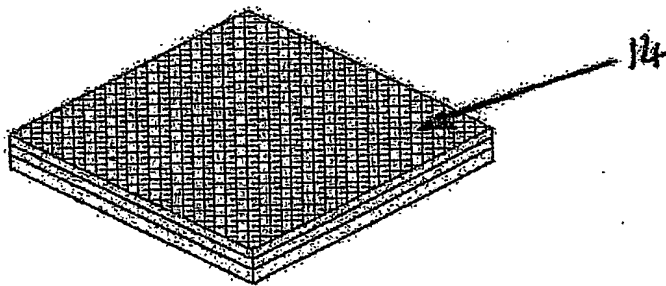
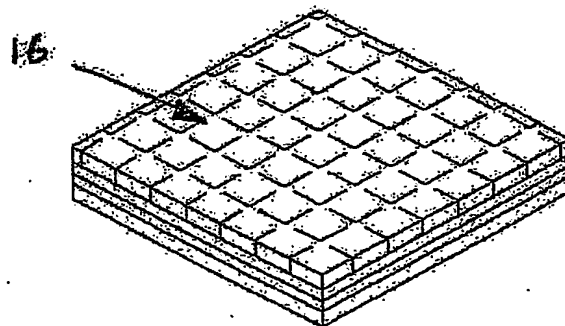


FIG. 4



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FIG. 5

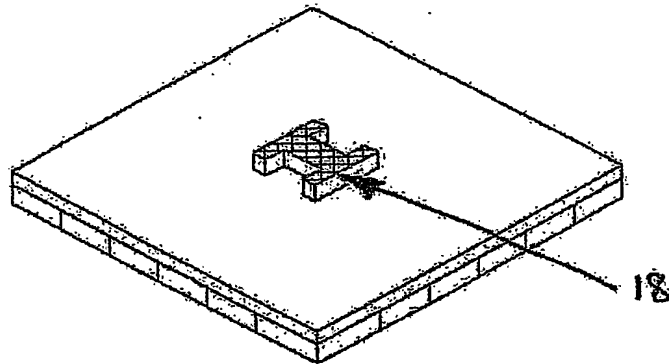


FIG. 6

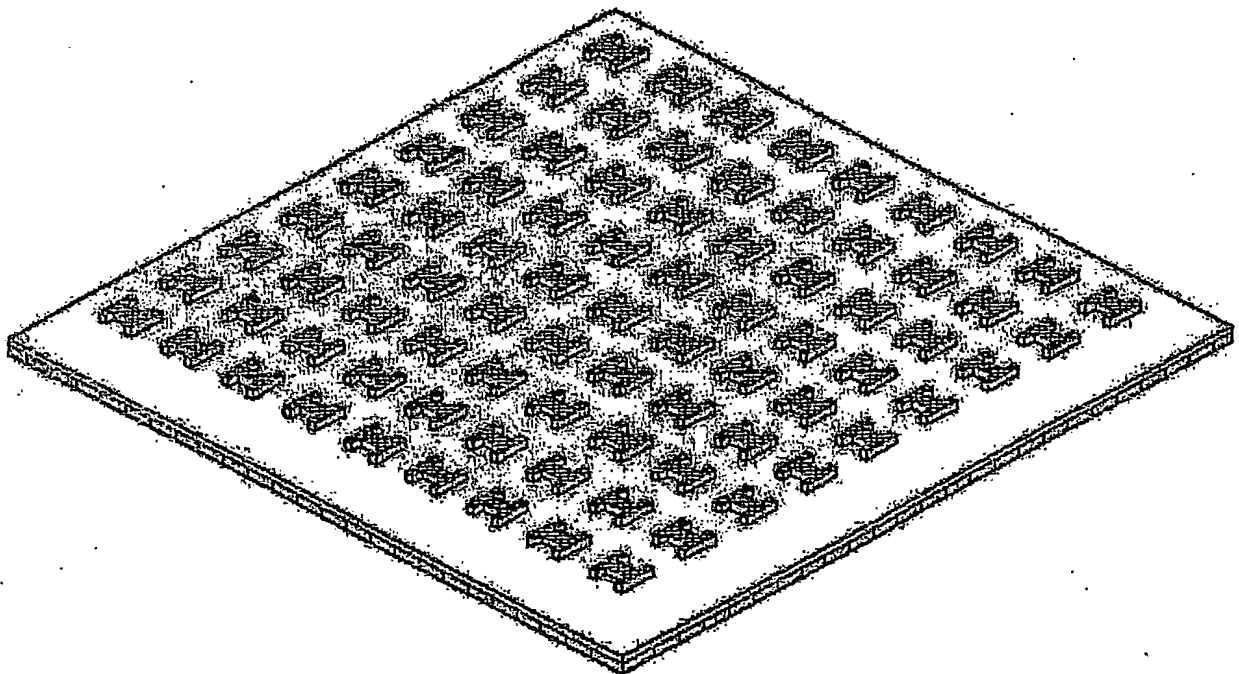


Fig. 7

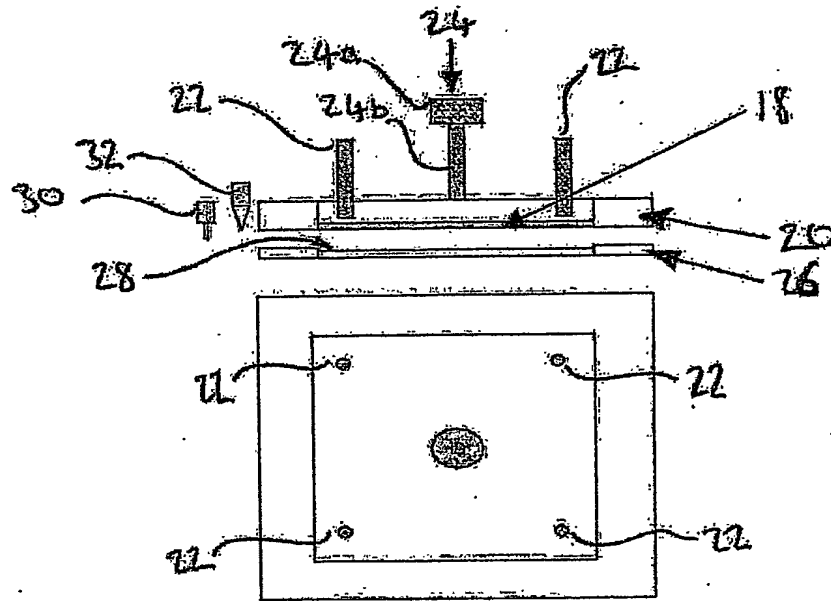


FIG. 7a

FIG. 7b

Fig. 8.

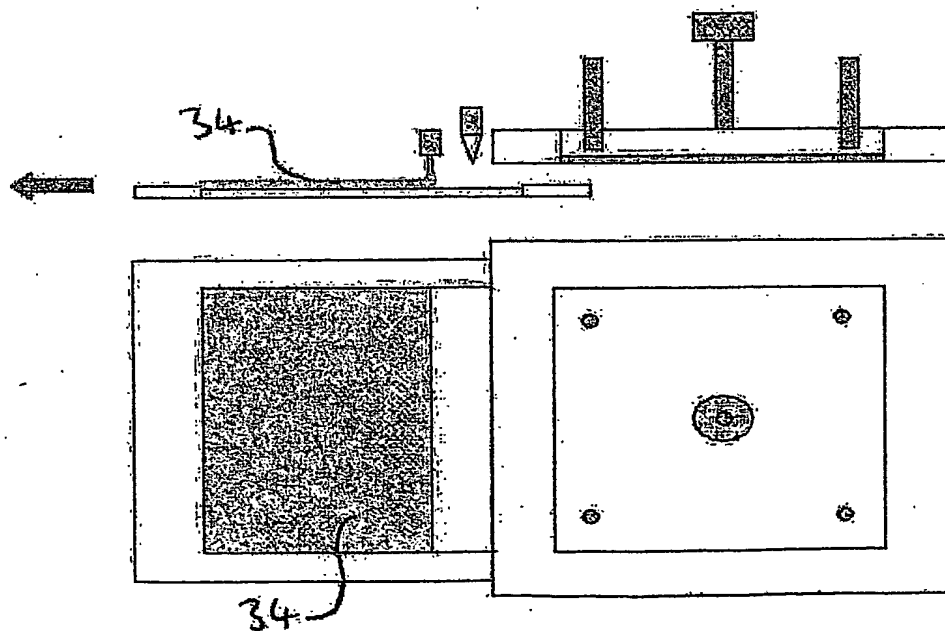


FIG. 8a

Fig. 8b

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FIG. 9

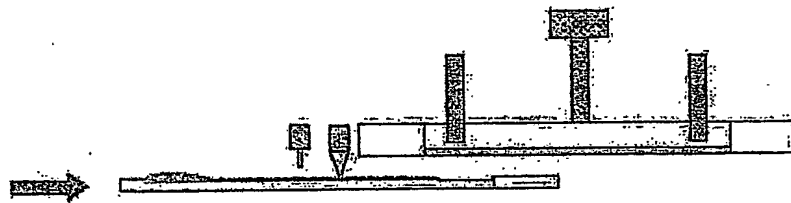


FIG. 9a

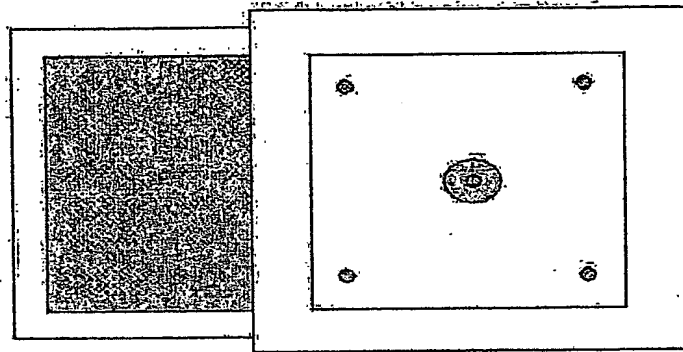


FIG. 9b

FIG. 10

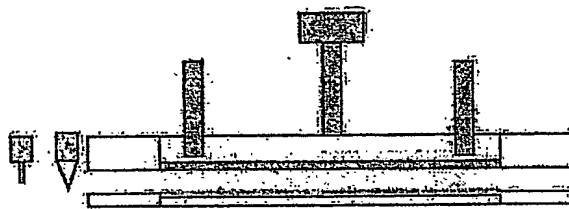


FIG. 10a

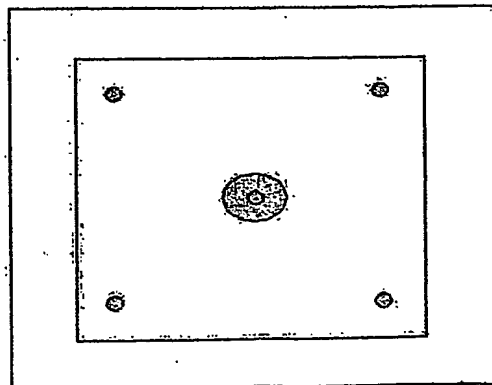


FIG. 10b

FIG. 11

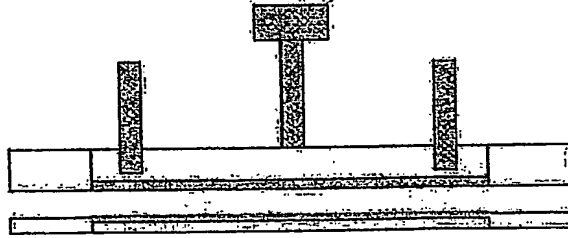


FIG. 12

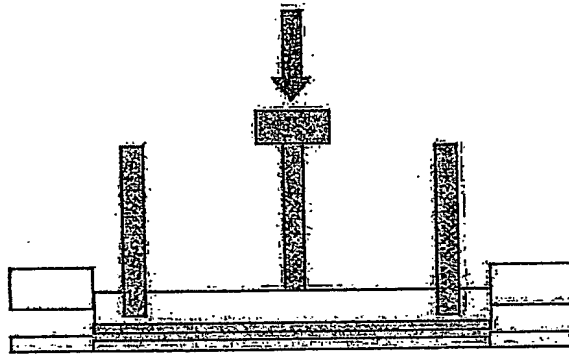


FIG. 13

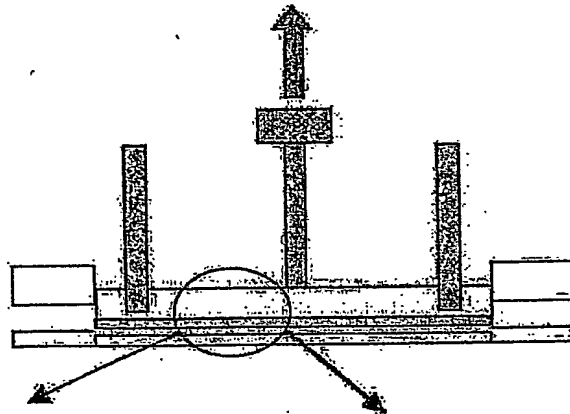


FIG. 13a

FIG. 13b

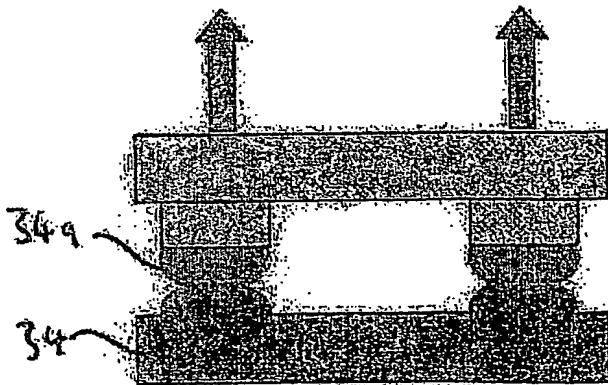


FIG. 13c

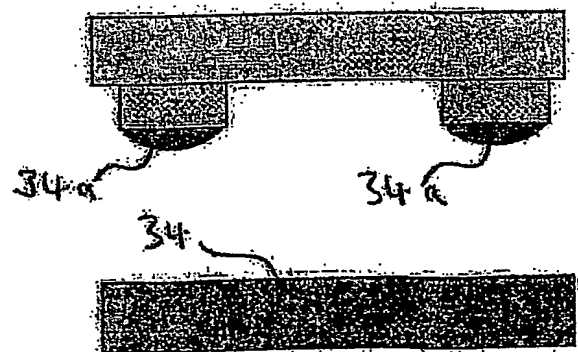




FIG. 14b

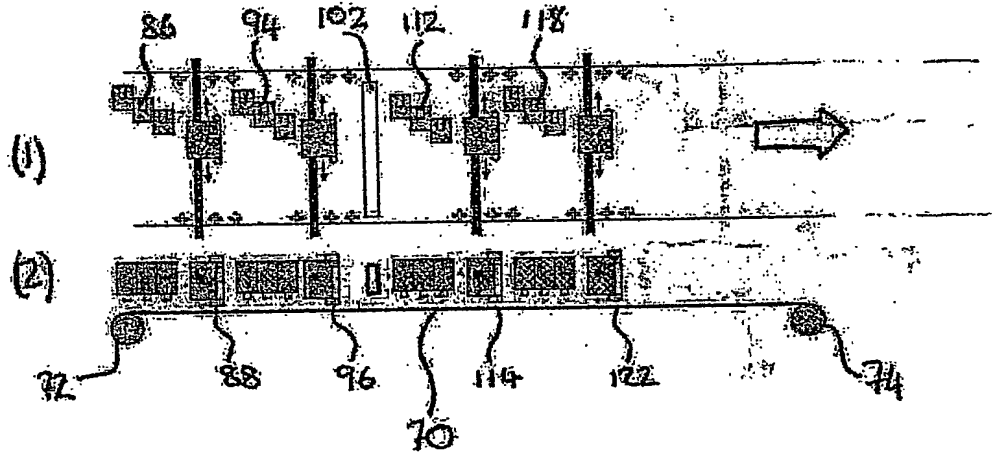


FIG. 14c

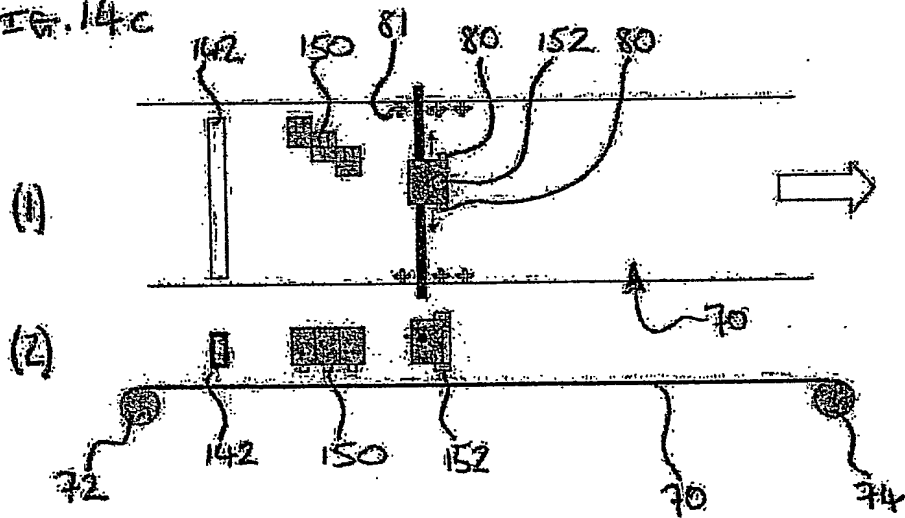
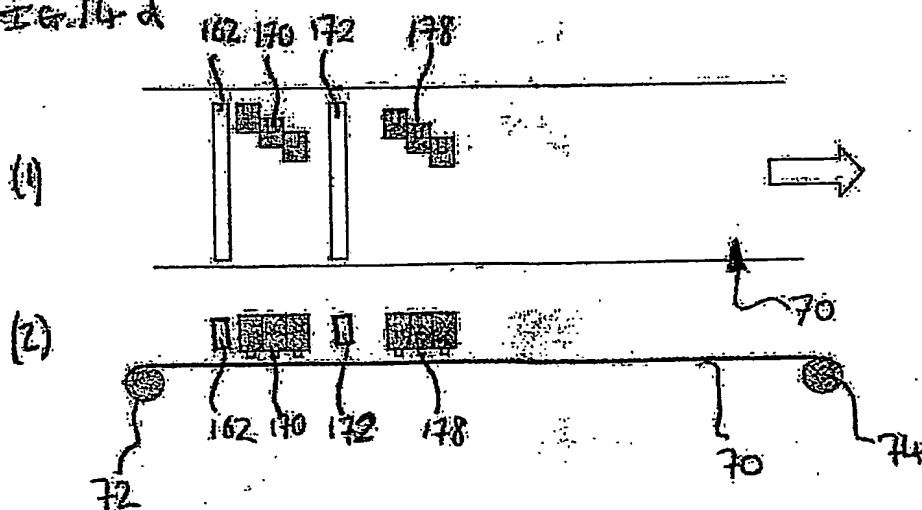


FIG. 14d



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Fig. 16a

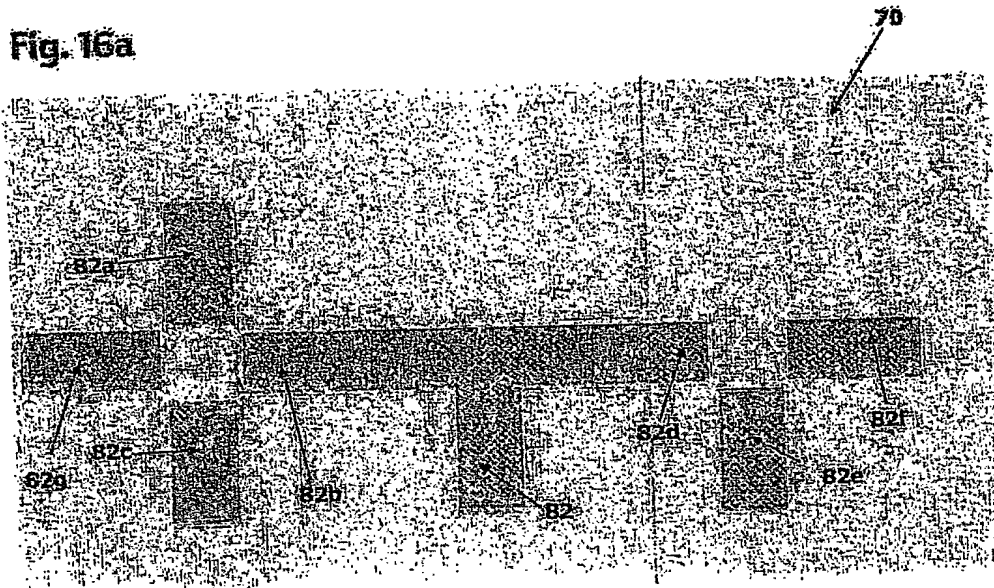
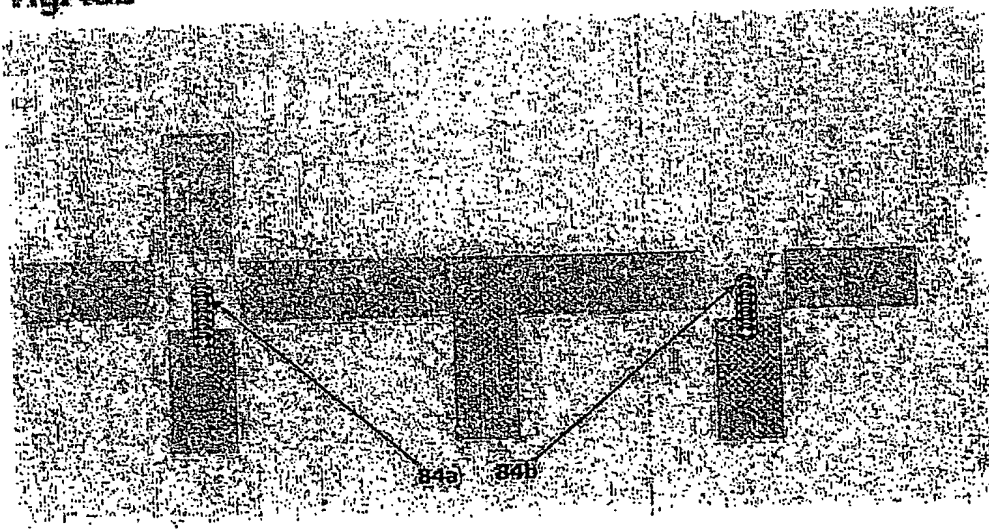


Fig. 16b



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Fig. 16c

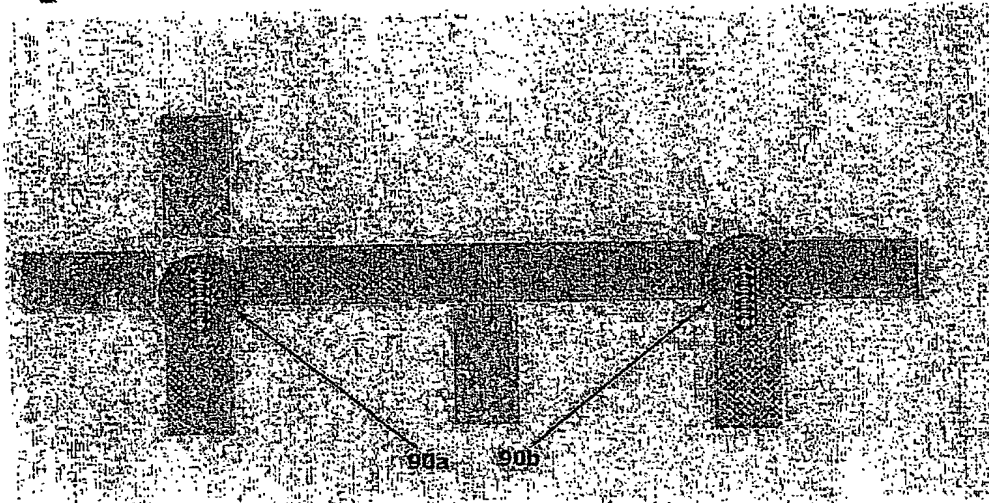
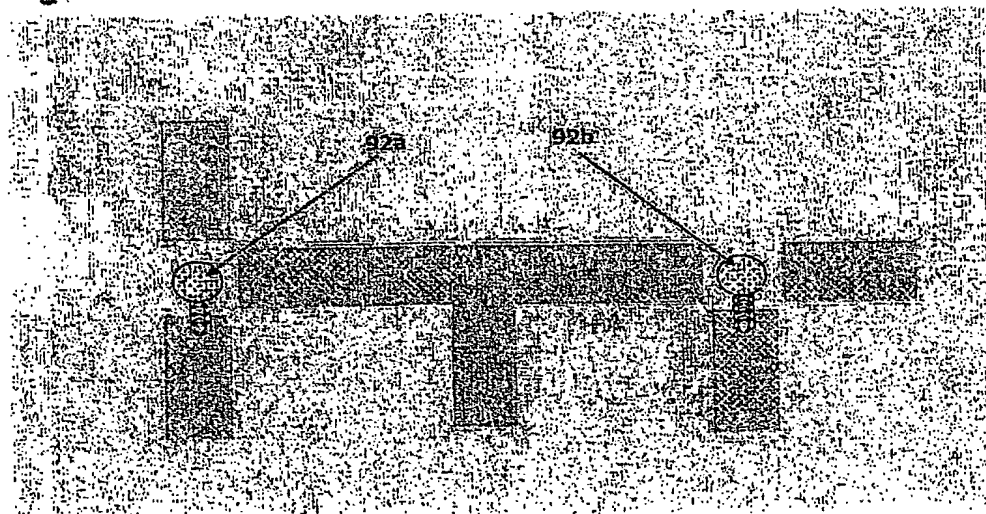


Fig. 16d



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Fig. 16e

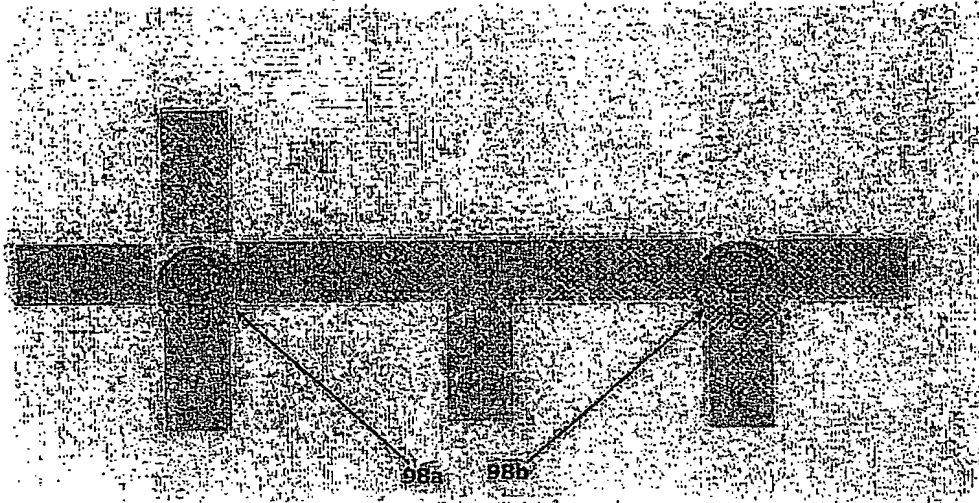
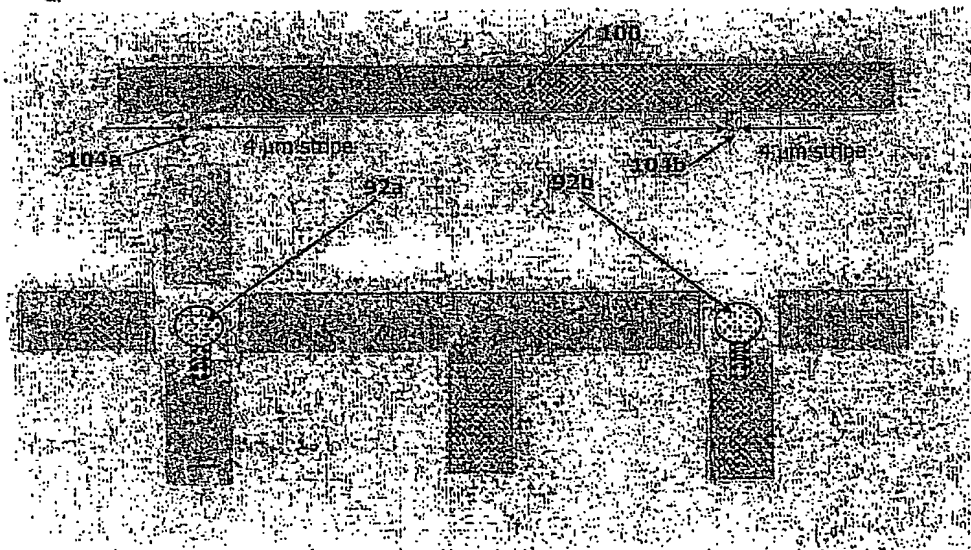


Fig. 16f



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Fig. 16g

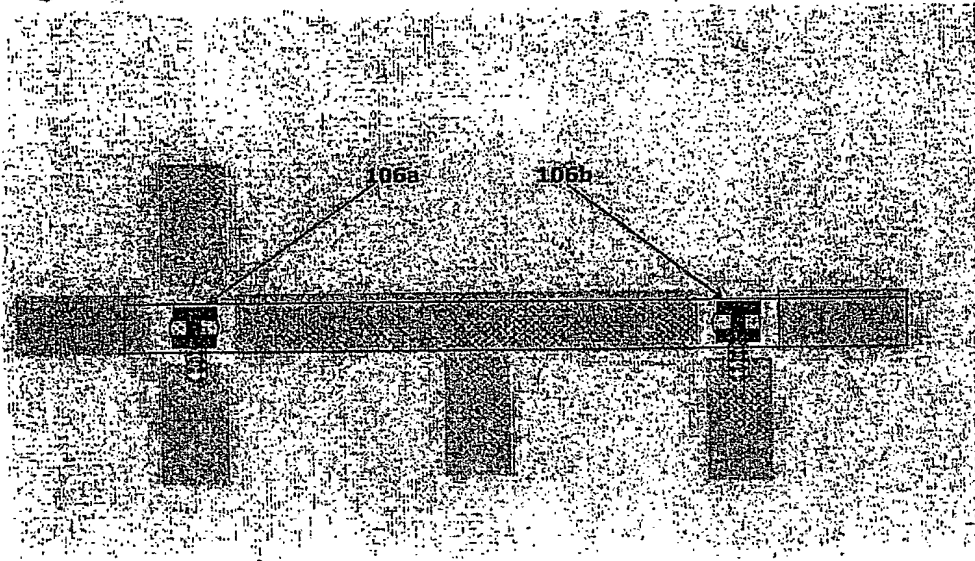


Fig. 16h

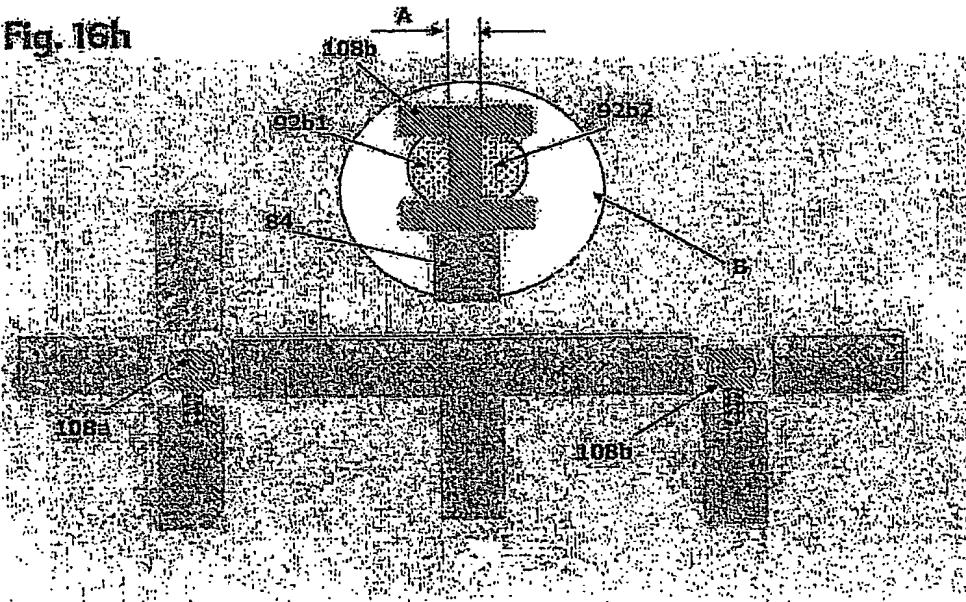


Fig. 16i

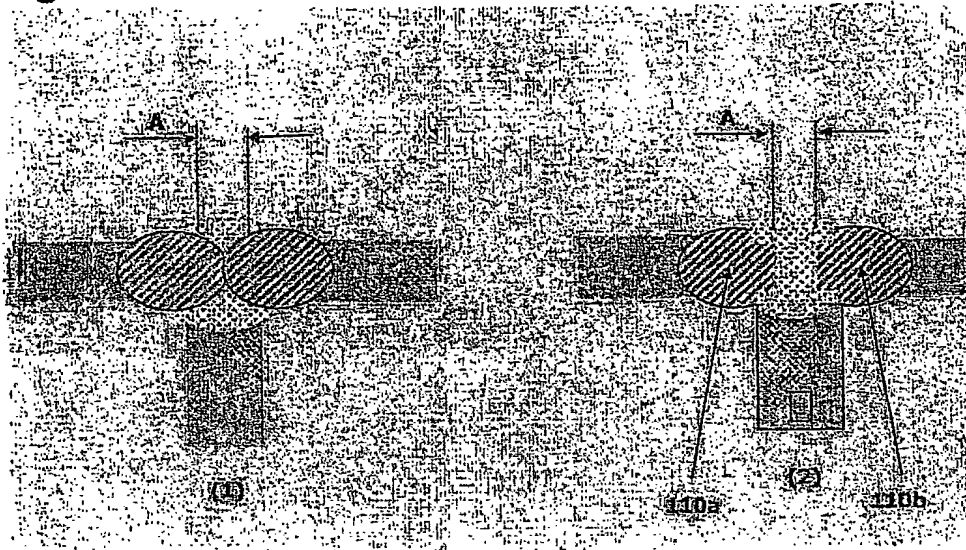
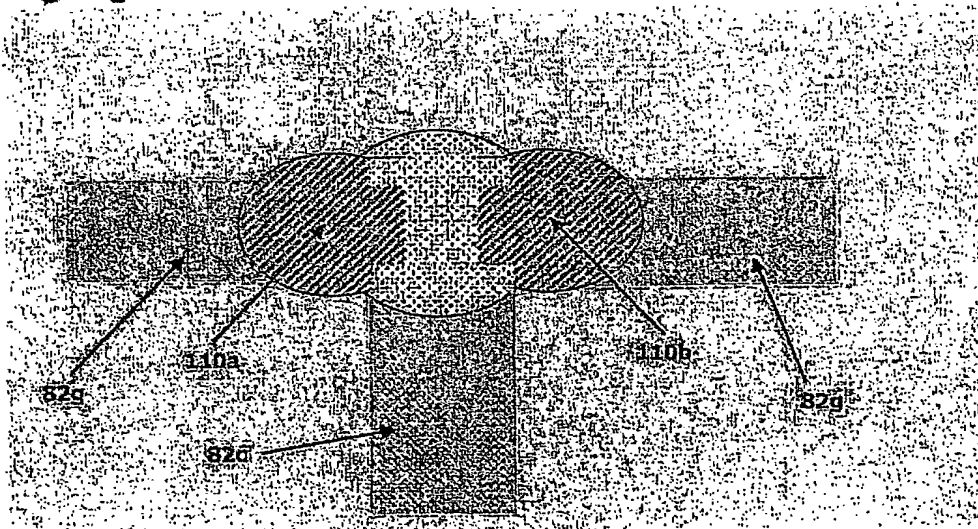


Fig. 16j



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Fig. 16k

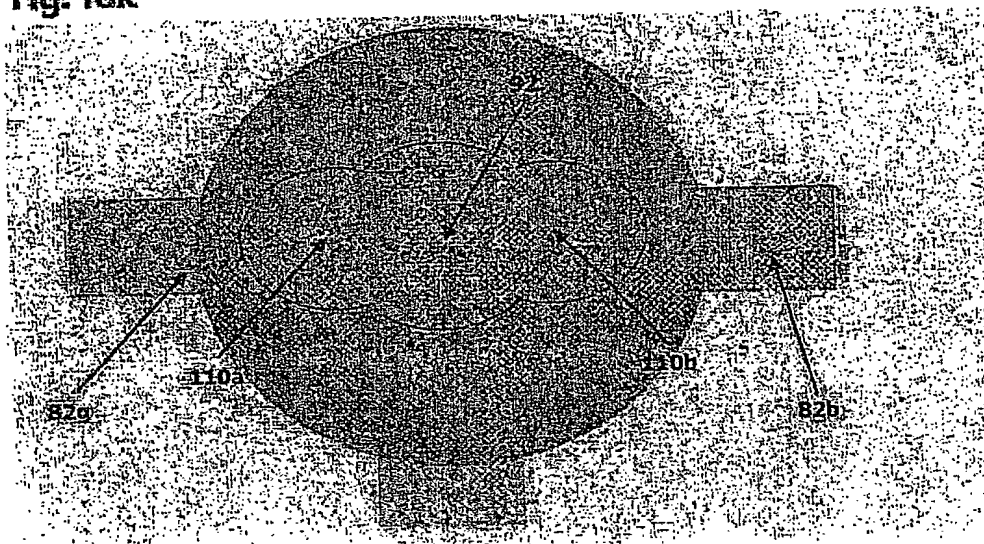
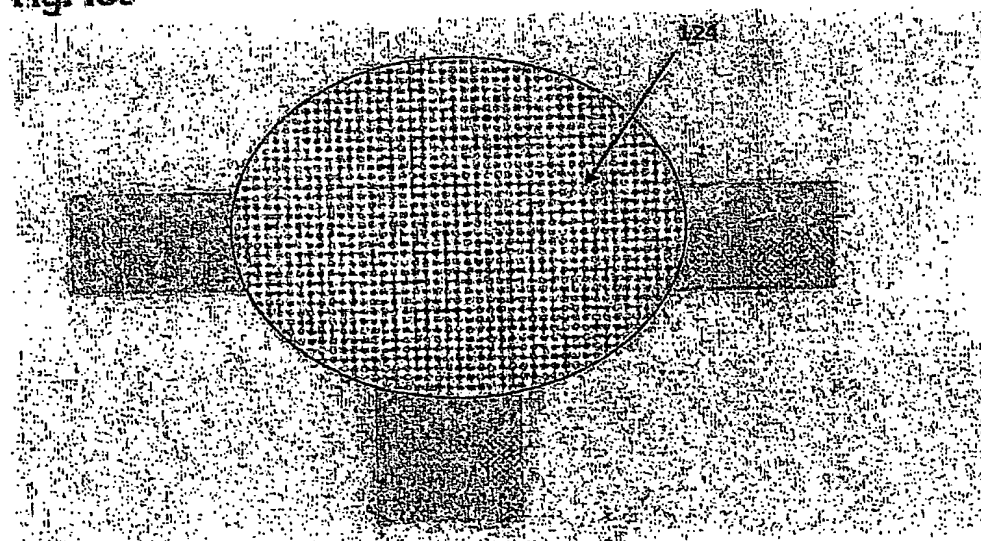


Fig. 16l



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Fig. 16m

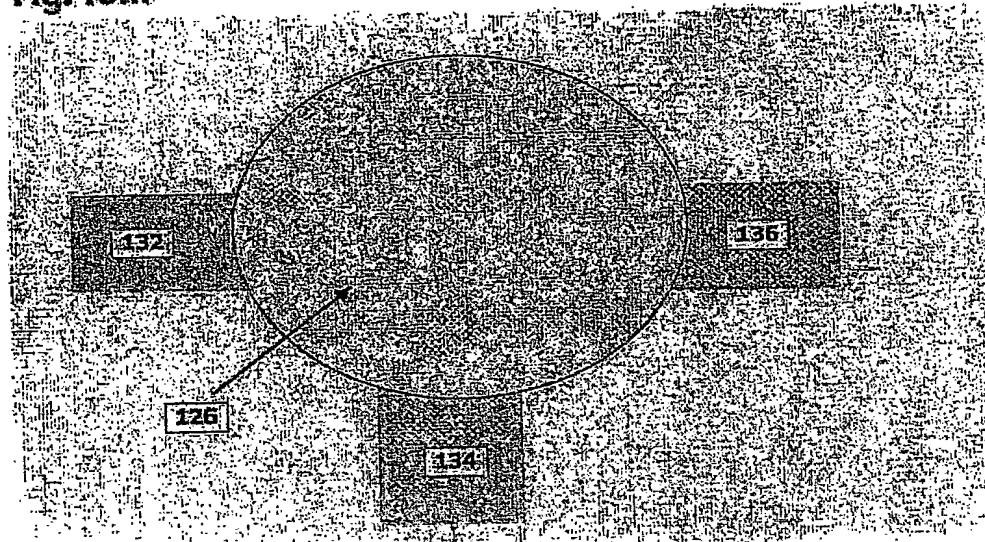
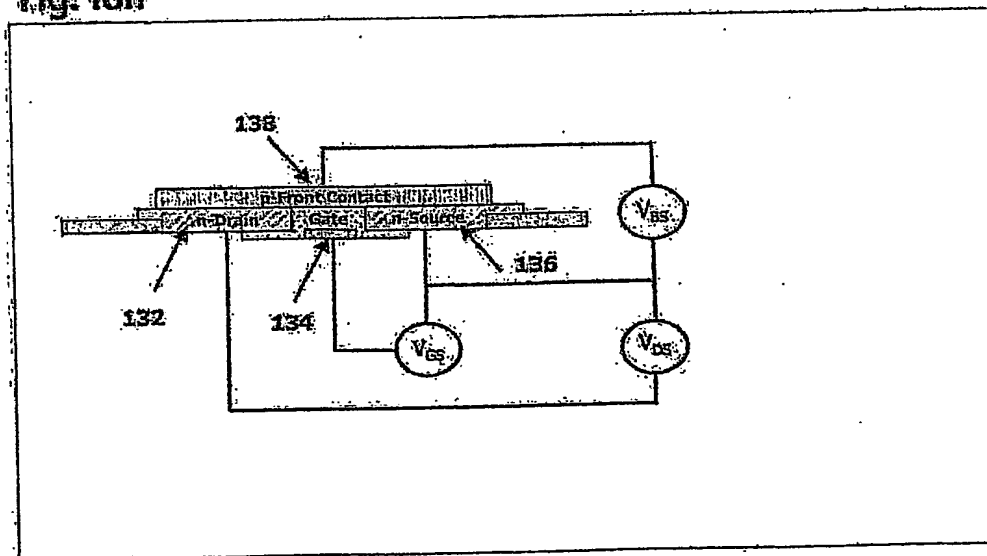


Fig. 16n



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Fig. 17a

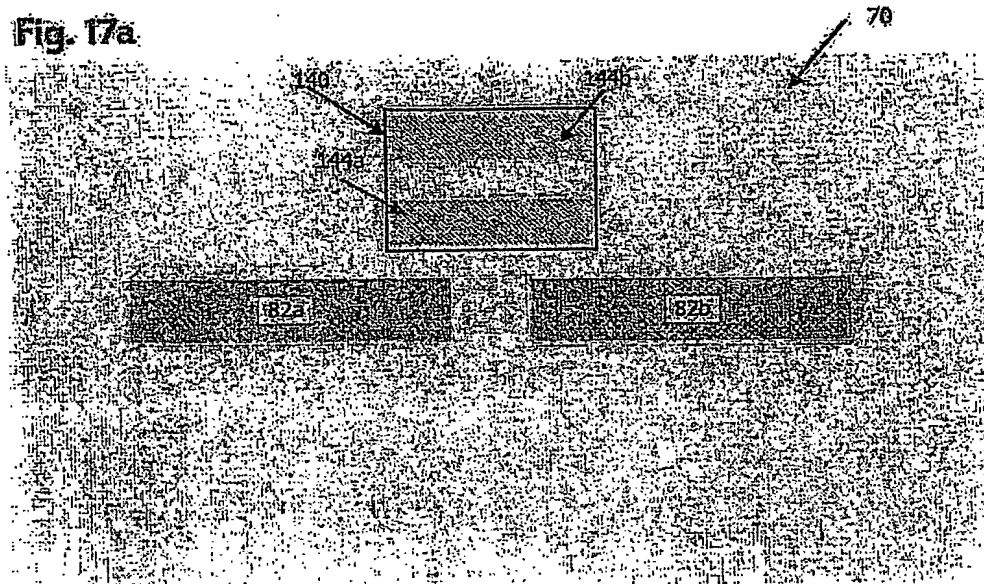
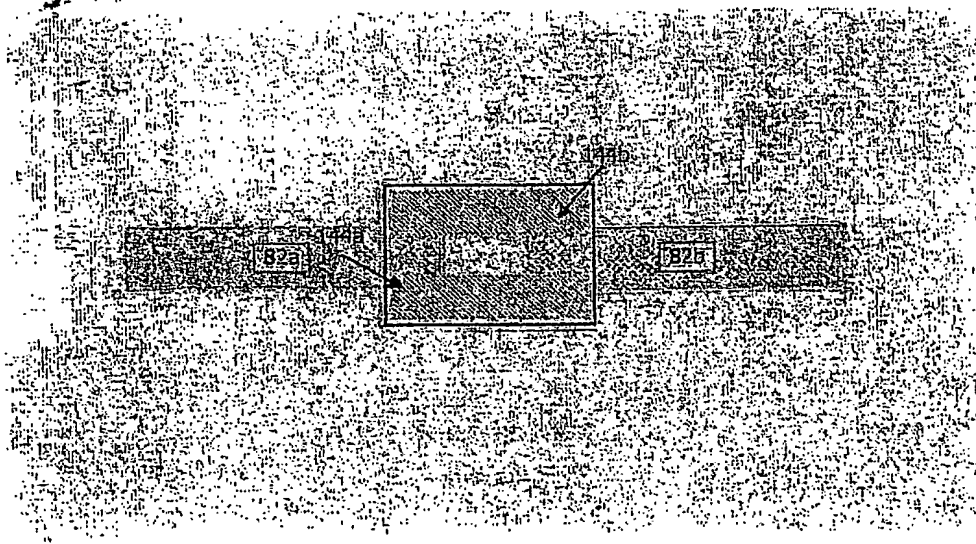


Fig. 17b



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Fig. 17c

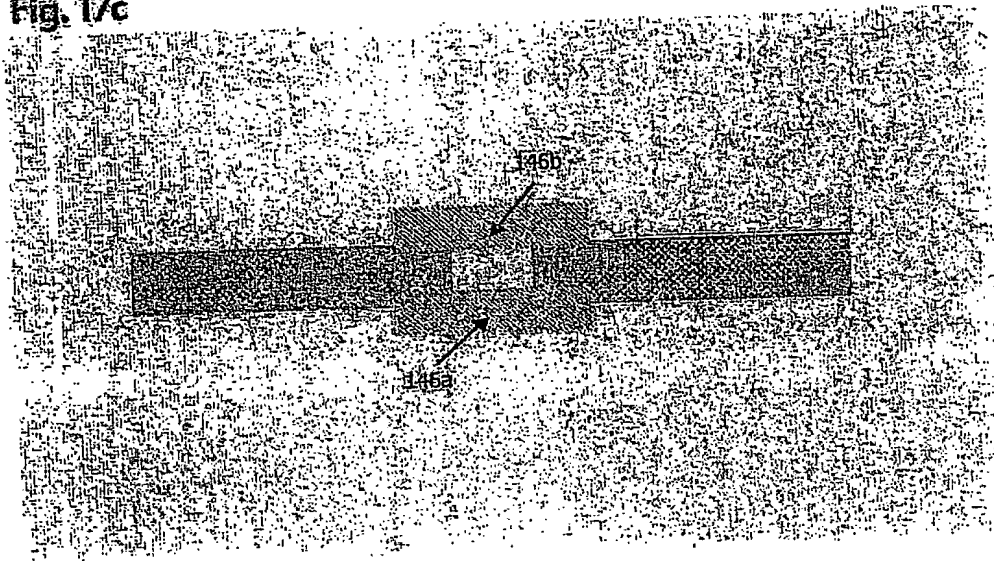
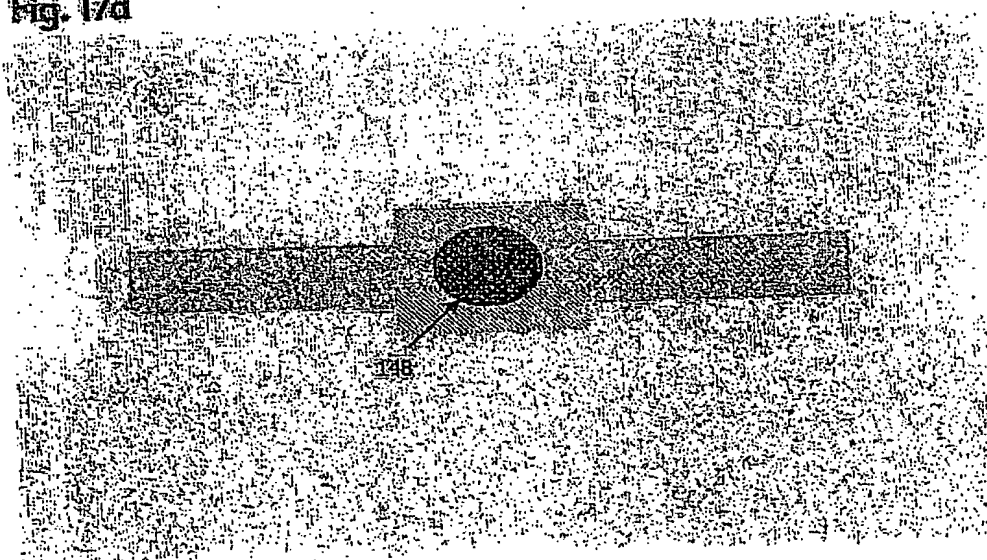


Fig. 17d



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Fig. 17e

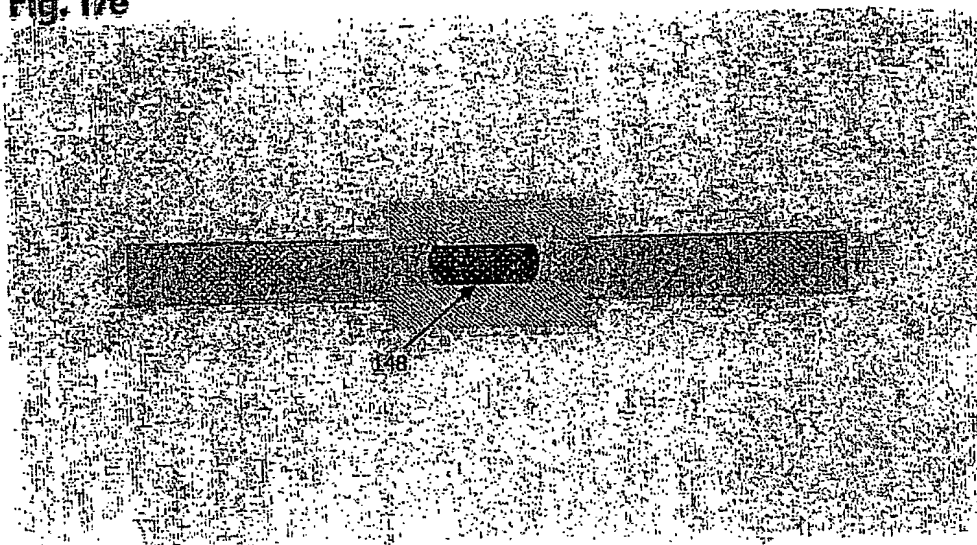
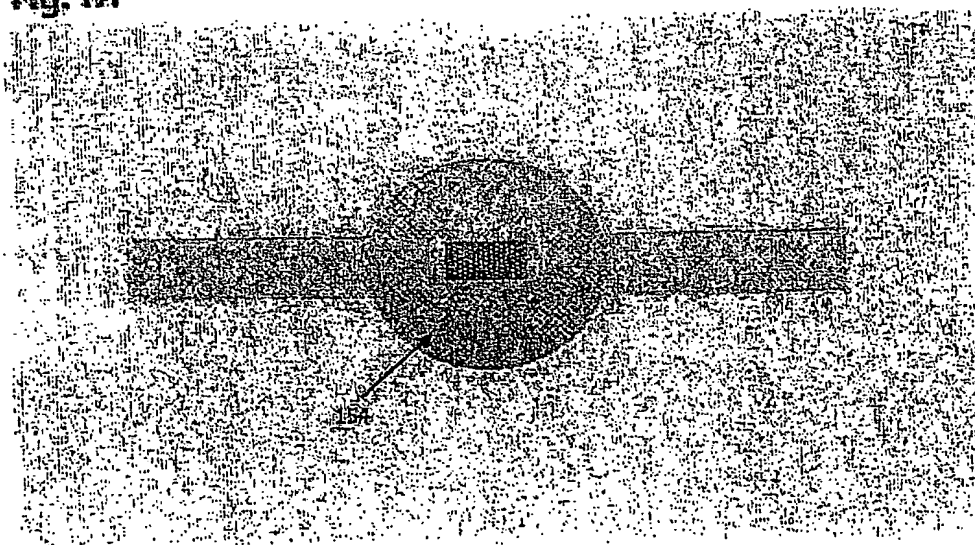


Fig. 17f



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Fig. 17g

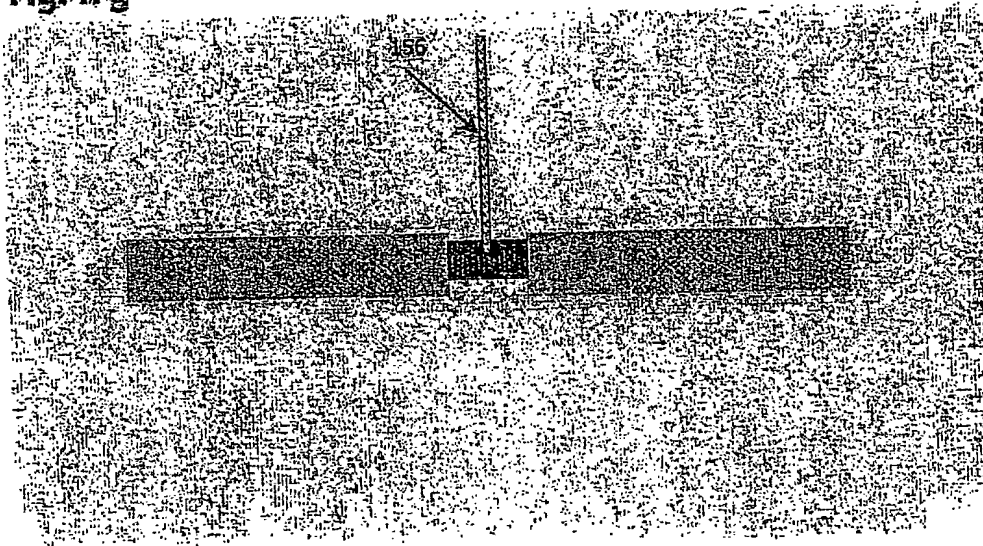
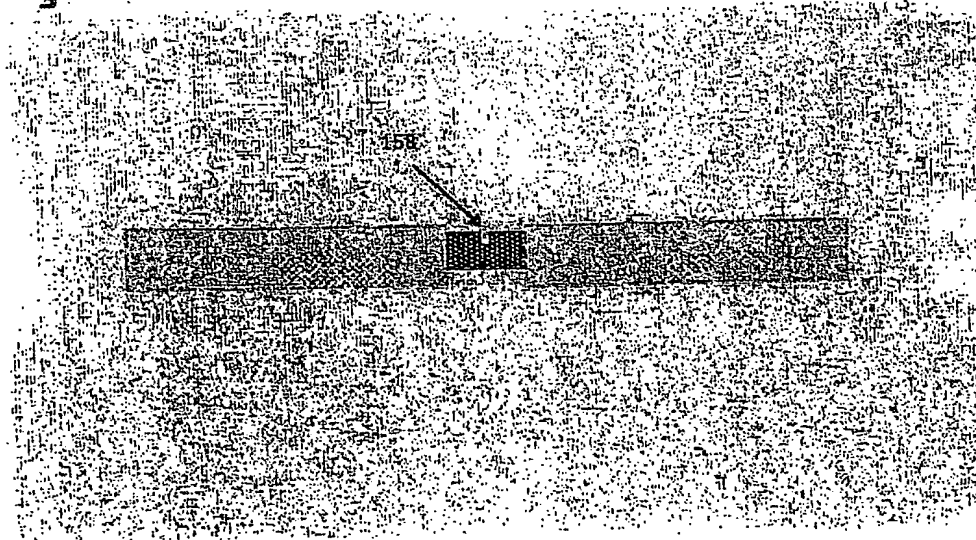


Fig. 17h



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Fig. 18a

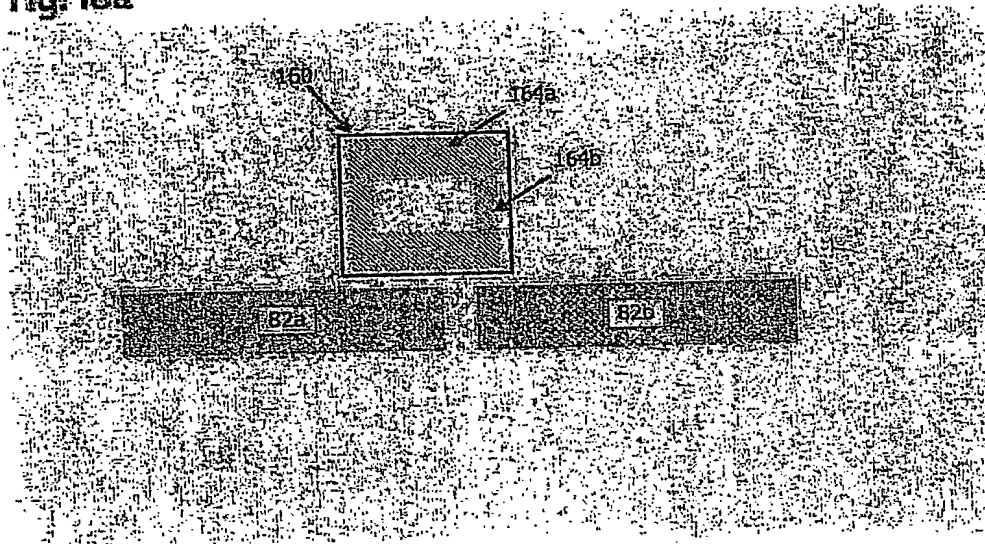
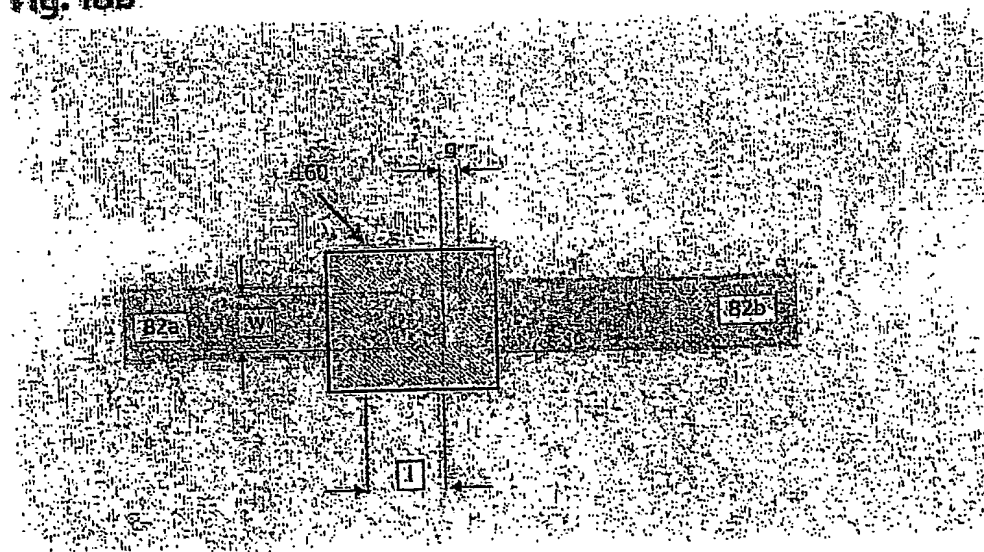


Fig. 18b



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Fig. 18c

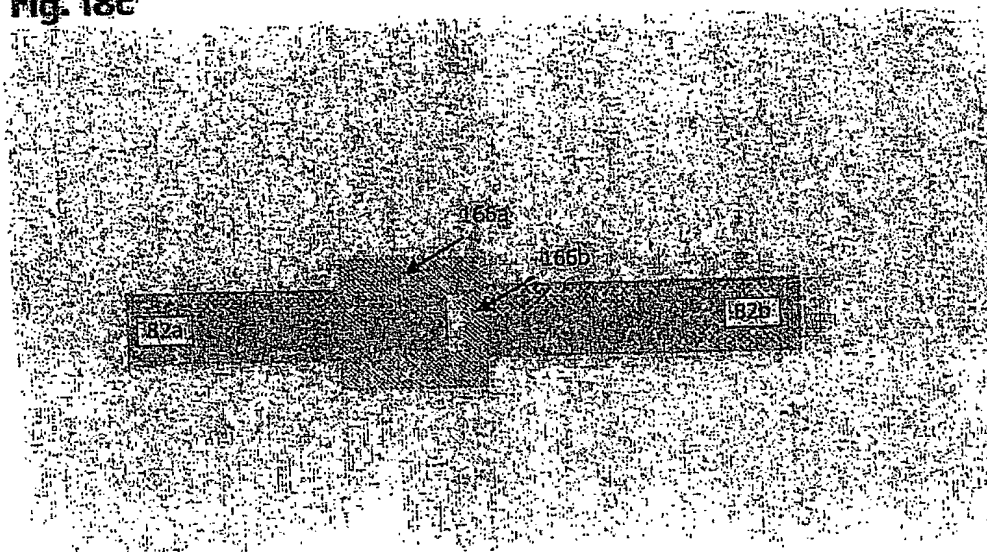
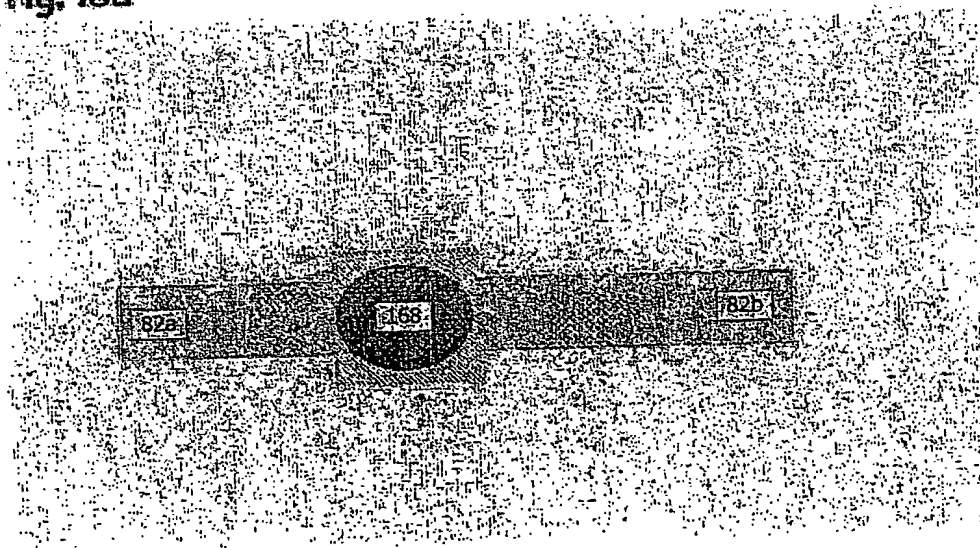


Fig. 18d



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Fig. 18e

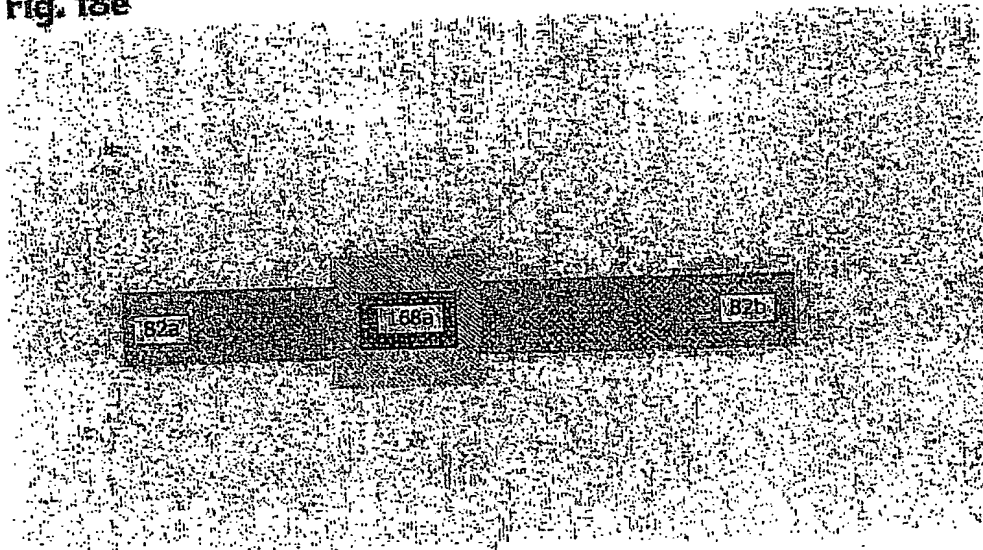
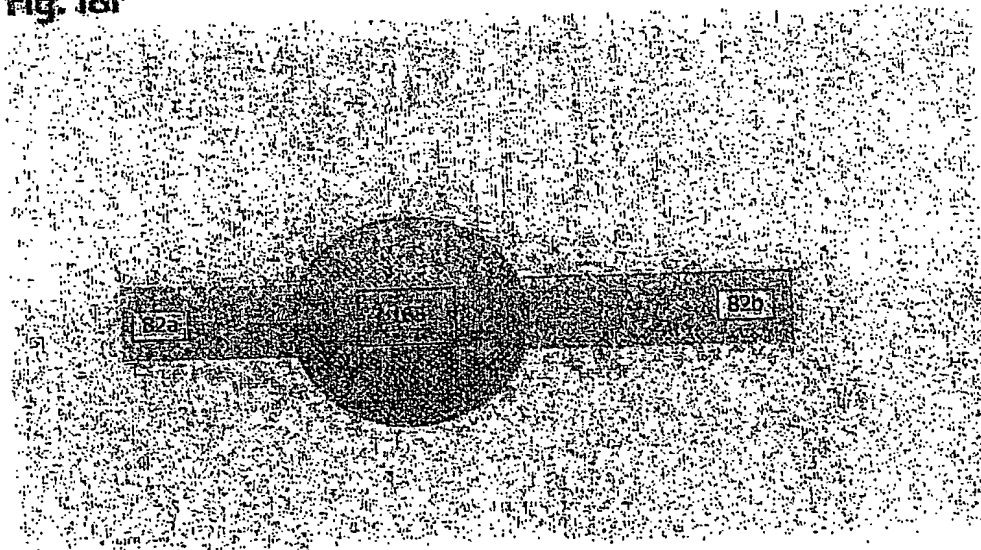


Fig. 18f



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Fig. 18g

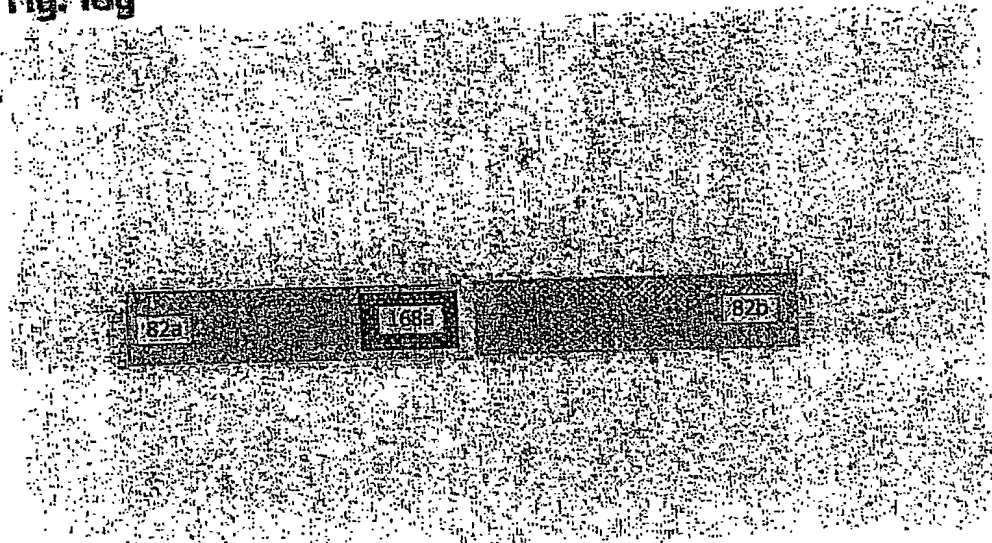
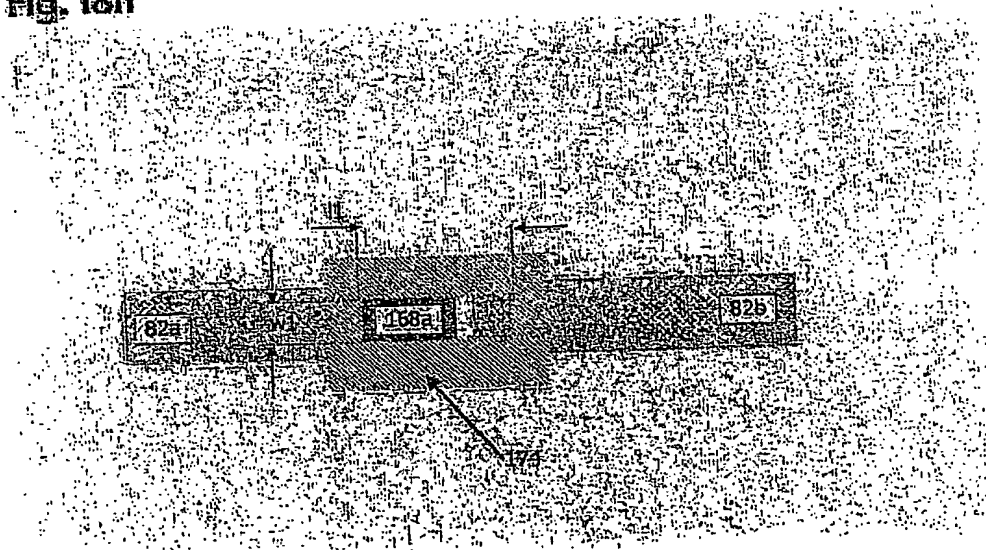


Fig. 18h



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Fig. 18i

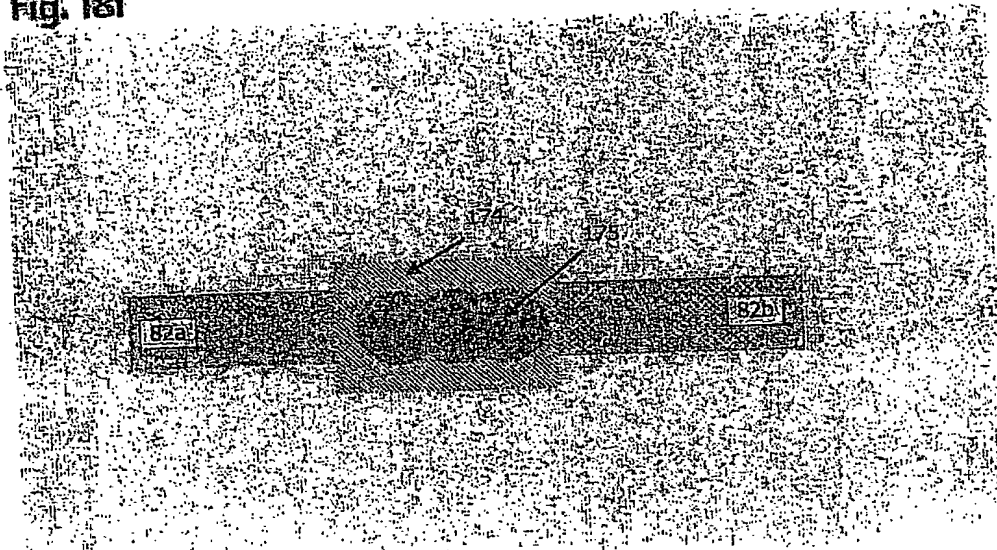
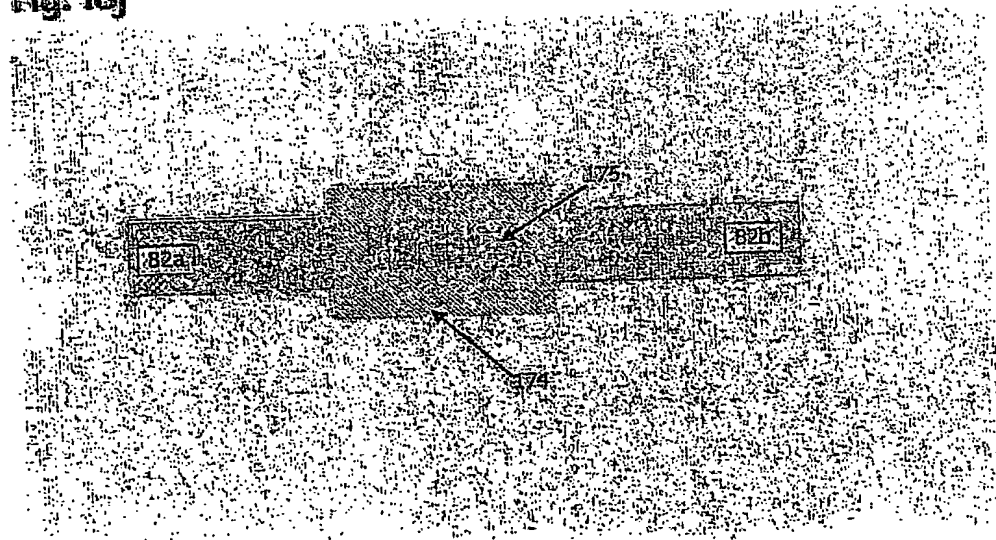


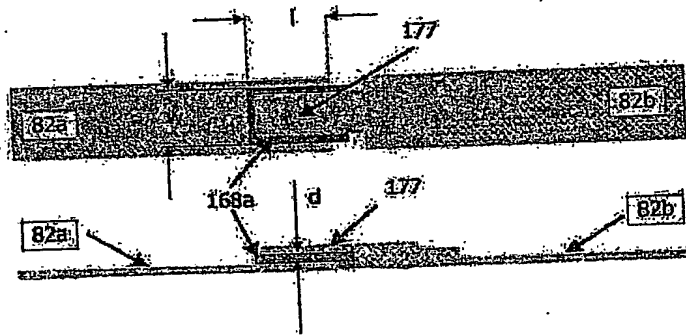
Fig. 18j



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Fig. 18k



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